Mullard

# THE MULLARD/PHILIPS RESEARCH LABORATORIES, REDHILL.

## A SHORT HISTORY 1946 - 2002

PHILIPS

John Walling MBE FREng

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Design and layout
Keith Smithers

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## A SHORT HISTORY 1946 - 2002

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This History is dedicated to all members, past and present,
of the Laboratory staff,
but most particularly it is dedicated to the memory of

Dr. PETER TRIER CBE FREng
(1919-2005)

Director of the Laboratory from 1953 to 1969

Photograph courtesy IEE Archives

# FOREWORD

When Ad Huijser (CEO of Philips Research at the time, now CTO of Royal Philips Electronics N.V.) asked me to succeed Peter Saraga as managing director of Philips Research Laboratories in Redhill early in 2002, I could not have imagined the changes that were to take place in the global electronics industry that would again dictate the future developments at PRL. Nor could I have imagined the speed at which these changes were to take place. The Internet bubble had just burst, the manufacturing electronics industry continued to move East at an even faster pace, there was even more consolidation in the "asset-heavy" manufacturing industry, e.g. flat screen displays and semiconductors, while there was an accelerated price erosion in the consumer electronics industry driven by digital commoditisation. Philips, as a global company, having anticipated some of these trends, was in a position to act swiftly and accelerate the implementation of some key strategic decisions and this in turn had implications for Philips Research.

The landscape in PRL was to change yet again as it had done many times before during its 60-year history. This is essentially the background for initiating this book – in an attempt to record the manner in which PRL transformed itself as a result of these industrial changes. Moreover, people are at the heart of Research – not only responsible for the creative output but also for implementing the changes based on a sound understanding of the industry trends and our internal businesses needs, and this book was to celebrate our people. It is thus intended as a tribute to the people who have made PRL the lab it is today, those who have contributed in different ways to its intellectual output, who were involved in 'historic firsts' and who have helped shape scientific and industrial developments over the years.

Writing such a history after 60 years is a daunting task. I was lucky to find John Walling, a former deputy director of PRL who was willing and able to write the book. I know he

was not alone, in that he used a network of ex-PRL people as well as archived documentation to reconstruct the history. While the history is to celebrate our people and it is difficult to single out anyone for particular merit, there is one person, whom unfortunately I did not have the opportunity to meet – Peter Trier, the second director of PRL – who deserves special mention and to whose memory this history is dedicated. Without his active contribution – despite his illness – it would not have been possible to have the result that we have today. He not only shaped the history of PRL in real terms but also greatly influenced the shape of this book. Nevertheless, it is not complete and not everyone will be mentioned – but then that was also never the intention.

The history of PRL (originally called MERL, Mullard Electronics Research Laboratory, PRL was first adopted on the 1st June 1977) mirrors the history of technology and the history of Philips growth during the last 60 years. It also reflects to a great extent the strategic thinking of Philips Research as a global organisation in accessing talent and expertise internationally. The main reason in the early days for having a research laboratory in the UK was the importance of accessing the UK expertise in areas where the UK was ahead of continental Europe. (in 1946 the key areas were those of Broadcast television, Microwaves and nuclear technology). There was a strong linkage between Research and the business and also a great many Government contracts, particularly in the area of defence. Today, exploiting our presence in the UK is again a key strategic issue for the laboratory in the UK albeit that the areas have changed and government contracts have been 'replaced' by EU subsidised projects.

During the intervening years, company growth and international developments meant that the lab moved away somewhat from the policy of "leveraging local expertise and environment". The growth of Philips in the early fifties led to a need for R&D resources and the re-orientation of the PRL Research programme from government-driven contracts to the Philips growth needs. The systems oriented research work extended to electronic devices and technologies, and ultimately to semiconductor and solid-state devices including magnetic materials. This was achieved with a corresponding growth in the research staff and an expansion of the site. Later on, the activities developed further to incorporate displays (from CRT's to LCD's, again mirroring the industrial developments!) and during more recent times included novel electronic systems for consumer interaction. This shows to some extent the transformations that the research work has undergone over the years.

Looking at all these developments (made much more explicit in the pages that follow),

we can identify the evolution of the current electronics world and the parallel need for different types of graduates – from physics and chemistry graduates to those in electronics and, more recently, computer science and software. PRL had a major strength in in-house "manufacturing" technologies (as evidenced by the linear accelerators, radar sonde, the maser amplifier for the Telstar satellite, the first transatlantic television transmission). Later on as the "knowledge" economy developed and the value of patents grew, PRL was quick to respond and today makes significant contributions to our patent portfolio in a few key areas, often driven into global (communication) standards. This also reflects the shift in value creation mechanisms over the years as well as the industrial deverticalisation that has recently taken place as a result of which Asia (China in particular) has become the manufacturing capital of the global electronics industry.

The notion of a Campus is not at all new to PRL, nor indeed the concept of open innovation. In the early days, MERL was co-located on the current Redhill site with the Vacuum Physics Laboratory. Although for most of the intervening years Research was "owner" and sole occupant of the site and later managed the services for all those who moved to the site, we have recently returned the site to Corporate Real Estate and once again are on a Philips Campus. PRL is no stranger either to Open Innovation (although it was not called that at the time!). An early example is the joint GEC/Mullard semiconductor company, ASM, that eventually led to the birth of the new factory in Hazelgrove. Today, one of the key challenges for PRL is use the current knowledge and business ecosystem in the UK so that we can further develop our programme in the current open innovation context.

We can also identify an early form of the "business rationale", where in an effort to get the programme under control in 1966, a 'top sheet' (that included information like rationale for the work, prospective benefit of the work for Philips, resources required, support services needed and other costs) had to be discussed with the Programme Planning Committee (a forerunner of the Research Programme Management team!).

There have also been the downturns, particularly in 1985, the early 90's and also in recent years. PRL has faced up to these issues in the mid-eighties and nineties (note that similar issues were evidenced in other industrial laboratories that had experienced rapid growth during the 50's and 60's) like an ageing laboratory, and a difficulty in transferring people to the divisions (as there was – and is today – a lack of Philips product divisions in the UK) – and continues to face these challenges as it again transforms itself to leverage its presence in the UK, while maintaining its appetite for discoveries that will contribute to the

future growth of Philips. However, looking again at the quality of our people and the desire to succeed – the heart and soul of any research organisation – I am confident that we will succeed – and this brings me back to celebrating the people over the past 60 years of PRL history.

I do not intend here to describe the details of the pages to come but rather identify a number of parallels with key developments in our industrial evolution and the growth of Philips. PRL has made significant contributions to this growth – as is evidenced later on - and it has been worthwhile to record these and also to highlight the people who made these contributions. So enjoy the pages ahead and I am sure that you will identify more parallels than I have mentioned in this short space.

Last but not least, I would like to thank John for taking on this daunting task. He has done an excellent job in networking, communicating, listening and writing but more importantly he was dedicated to the job. When most people would have given up, he remained enthusiastic and full of energy, focusing on getting the job done.

I am proud to be part of Philips, proud to have initiated this work, and above all, proud to be the current custodian of such a great tradition.

Dr. Terence Doyle,
Managing Director Philips Research Laboratories

# PREFACE

It was at the end of 2003 that Dr. Terry Doyle, currently Managing Director of Philips Research in the UK, conceived the idea of a History of the Laboratories. It was a very good idea as the achievements of the Laboratory over the nearly sixty years of its existence, together with some portrayal of its staff were eminently worth recording and bringing together in a single volume. Terry asked me whether I would consider trying to assemble such a record and early in 2004, feeling rather pleased to have been asked, I agreed to do so and this volume is the result.

From the outset I realised that it would be a big task and so it has proved. I have done my best; however, I have not tried to provide an encyclopaedic record, rather, I have selected activities which I considered to illustrate the style of the Laboratory and its people at the various stages of its evolution. Many items, of course effectively chose themselves as outstanding, epoch making, achievements. Unfortunately rather few records of the early history of the Laboratory have survived and therefore a good deal of the content of the first few chapters is based on the recollections of various individuals of those times, including, I hope not too disproportionately, my own. In addition to the personal contributions which I received, I have drawn on various summary publications, particuarly those in Philips Technical Review. The Annual Reviews (published from 1968 to 1991) have also been invaluable sources. The History is not intended to be a technical or scientific treatise but from time to time I have included some technical background to the extent that it seemed necessary to an understanding of the nature of the work and what was achieved.

Any selection process is inevitably subjective and to some extent unfair and I am unhappily conscious that many notable activities and those responsible for them have received no mention at all or have just been referred to in passing. To those concerned in such work who feel disappointed at not being included I offer my sincere apologies and ask

for their understanding.

I have received a tremendous amount of help and advice from a great many people including (in no particular order) the following:- Steve Robinson, Bryan Overton, Cliff Braybrook, Brian Evans, Norman Goddard, Kurt Hoselitz, Peter East, Peter Bunn, Brian Minnis, Chris Marshall, Gordon McGinty, David Allen, Brian Manley, George Weston, Ken Freeman, Ted Eilley, John Orton, David Paxman, Bruce Joyce, Simon Turner, Paul Gough, Alan Knapp, Steve Pitchers, Tony Crossley, Peter Saraga, John Bunton and Peter Trier. I acknowledge, most gratefully, the generous help that each of them has given to me.

Peter Trier's contribution calls for special mention; he was quite delighted that a history of the Lab was being written and he read, and commented on, every chapter as I wrote it. This included the last chapter, which I discussed with him at the end of February 2005, a few weeks before his death. It was Peter who provided me with the details of the organisational machinations described in the first two chapters and, indeed, only he could have done so. All his carefully considered comments were of the greatest value and it is a matter of very great sadness to me that he did not live to see the book in its final form, well illustrated and formatted as it is.

In that connection Keith Smithers was responsible for the very considerable task of formatting the text which he undertook with professional skill coupled with great care, patience and enthusiasm. I acknowledge his vital contribution with most sincere gratitude.

David Paxman and Brian Manley valiantly undertook the task of reading the proofs of the book; each of them also made valuable editorial comments as has Terry Doyle also. These gentlemen are therefore listed as Editors and I am most grateful to them.

In conclusion I would like to say that I have felt very privileged to have been given the opportunity to record something of the history of this great Laboratory in which I had the good fortune to spend my working life. For many, these pages will evoke nostalgic memories, for others the content will be largely new. In either case it is my earnest hope that you will find reading this book to be as rewarding and worthwhile an experience as writing it has been for me.

John Walling.

# The Author
# a biographical note

John Walling joined the Laboratory in October 1952 having been awarded a PhD in Physics by the University of Leeds. He worked on Microwave Tubes in the Vacuum Physics Laboratory until 1957 when he transferred to Solid State Physics. Here he initiated the programme on solid state masers which included the devices successfully used in the first transatlantic television transmissions during the Telstar experiment in 1962.

He was appointed an MBE in January 1965 and later that same year succeeded Dr. Kurt Hoselitz as Head of the Solid State Physics Division, a position which he retained until 1988, being appointed as a Visiting Professor in the University of Surrey in 1975 and Deputy Director of the Laboratory in 1978.

In 1988 he was appointed as Senior Consultant and worked under contract to the Science Research Council as Co-ordinator of the UK Inter University programme on Low Dimensional Structures, a role in which he continued as an Independent Consultant following his retirement from Philips in 1990.

He is a Fellow and former Vice-President of the Institute of Physics, a Fellow of the Institution of Electrical Engineers and a Fellow of the Royal Academy of Engineering to which he was elected in 1983

## CHAPTER ONE

# EARLY DAYS 1946 - 1952

### THE BEGINNINGS

The Mullard Research Laboratories which, some years later were to be renamed the Philips Research Laboratories, were established in November 1946 on a site in Salfords to the south of Redhill in Surrey to serve the Mullard Radio Valve Company. The Mullard Radio Valve Company was a subsidiary of Philips Electrical Industries, in its turn a wholly owned subsidiary of NV Philips Gloeilampenfabrieken of Eindhoven in the Netherlands.

At that time there were already several laboratories within the Mullard organisation undertaking what were essentially product support activities. Amongst these were the Central Materials Laboratory, The Vacuum Physics Laboratory and a small applications Laboratory, each of which was largely based in the enormous Mullard factory complex at Mitcham. In broad terms these laboratories were concerned with materials and factory processes, electronic device design, and with new applications for the devices. There were also small development and applications laboratories in Wandsworth, Bournemouth and Balham. Why then a further laboratory?

The answers to this question are fairly clear. Mr. SS Eriks, the then Mullard Managing Director (he was also Chairman of Philips Electrical Industries), considered it vital for the future of the Mullard Company that it should have an effective, well managed, well resourced and broadly based British laboratory. During the Second World War the Mullard Company was regarded as a foreign owned enterprise* and, despite being a major supplier of more conventional valves (most notably the EF50) and components, had not had a significant part in the colossal Government funded development of electronic devices and systems, particularly at microwave frequencies, on which its competitors had thrived. A further reason for this was undoubtedly the lack of a sound, coherent UK research facility. Eriks saw that such

*Mr. S.S. Eriks*

* *Shortly before the outbreak of hostilities in Europe at the beginning of the Second World War, Philips, foreseeing the German occupation of the Netherlands and wishing to avoid its UK assets being sequestrated by the UK Government as enemy property, had vested them in a Midland Bank Trust Fund. A similar arrangement was made in the USA.*

a laboratory would provide the opportunity, which the existing fragmented and indifferently staffed laboratory facilities did not, for the Company to obtain contracts from the British Government for research into electronic devices and systems. Clearly such contracts would enable the Company to access the vast UK expertise in the field and to gain a share in the substantial funding, which was apparently available. Other factors, at least as weighty, which influenced Eriks's decision, were that, at that time, the British had substantial leads over Europe in the areas of broadcast television and of nuclear technology. This know-how, vital to the future of the business, as then perceived, might be accessed and exploited very effectively by a new, UK based, laboratory.

The need for the laboratory was called into question by Philips in Eindhoven where the established view was that the research needs of the Concern could fully be met by the Nat Lab (Natuurkundig Laboratorium) in Eindhoven. Eriks' arguments concerning the importance of accessing UK expertise in areas where it was far ahead of Continental Europe were, however, undeniable. In any case he proposed, initially at least, to fund the whole thing from UK Group resources with the expectation, in due course, of substantial Government funding. The Philips management therefore agreed to let the scheme go ahead, possibly regarding it as an interesting experiment. This agreement was, in fact, in accord with a wider Concern Management policy, in the early post war period, under which the National Organisations within Philips were allowed a great deal of local autonomy, provided that they were financially sound and paid for the services provided by the Concern Centre. Another factor, which undoubtedly provided strong motivation for Eriks' wish to establish a new laboratory, was to be found in the manner in which the UK Group Board was organised. It comprised three directors, Mr. Eriks, the Commercial Director, Mr. FA Kloppert, the Technical Director, and the Financial Director, Mr. R van Eyle. Each director was answerable separately and independently to his counterpart on the Dutch Board of Philips – the Raad van Bestuur. Thus Kloppert was responsible for the factories and the laboratories within them and Eriks, despite being Chairman of the Board, in practice had no independent say in their activities. Therefore, fulfilment of his wish to broaden the commercial base of the Group and access UK expertise through research demanded that he set up his own facility, independent of those in the factories.

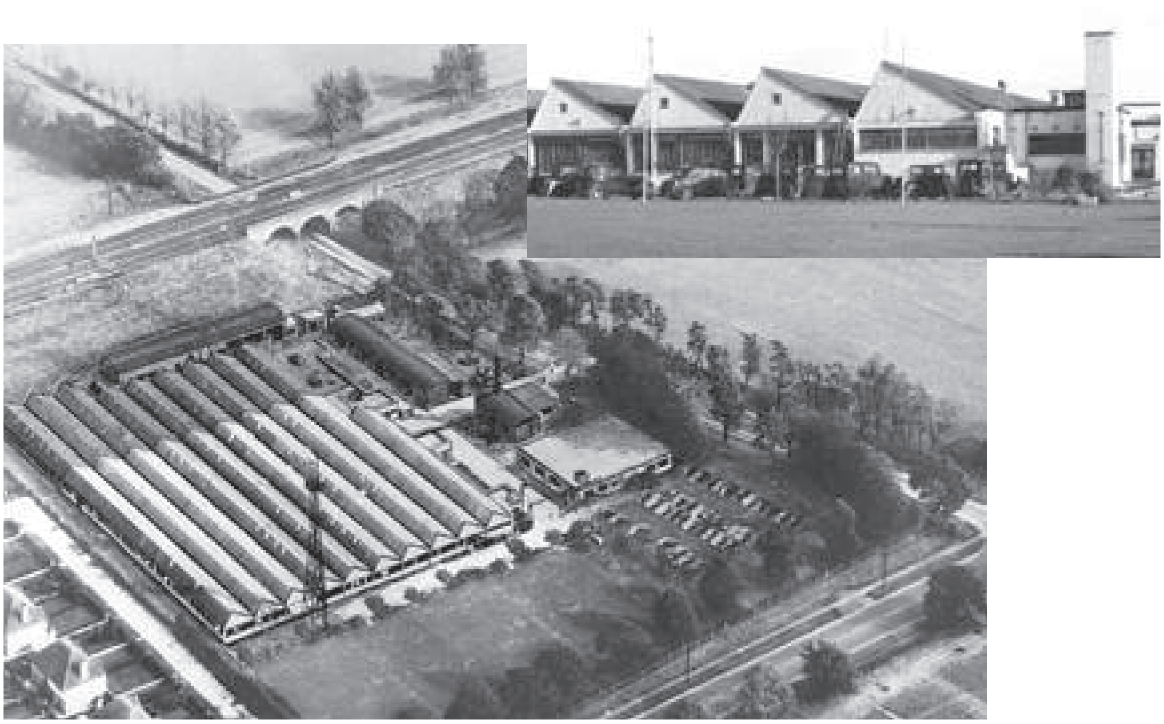
Thus, towards the end of 1946, the new laboratory, the Mullard Electronic Research Laboratory MERL, came into being in part of a rather shabby single storey factory building at the junction of the A23 and Cross Oak Lane in Salfords. The rest of the building was

occupied by a small Mullard production unit, some other Mullard offshoots and a furniture company.

The newly appointed Manager was Dr. Christopher Bareford, a graduate of Sheffield University, who had formerly held a senior managerial post in the Admiralty Signal Establishment in Haslemere. Towards the end of the war Bareford had conceived an ambition to set up and manage an industrial electronics laboratory in the post war era. He had discussed the possibility with Ferranti and also with Mullard (via Cdr Hugh St.A Malleson RN, a pre-war member of Mullard who rejoined the Company after the end of hostilities). Malleson's awareness of Bareford's interest proved particularly timely resulting in his appointment to MERL. Norman Goddard, who knew Bareford for many years, comments as follows:- " Bareford was a strong but unusual character. He was a brilliant laboratory innovator but his personality was not conducive to the effective management of a maturing organisation. He was fiercely loyal to his own staff but his uncompromising expression of his opinions frequently led him into conflict with his superiors."

*Dr. C.F. Bareford*

John Bunton, who was the Mullard Company Secretary for many years, supports Norman's assessment of Chris Bareford adding, with some regret, that Bareford was a man



*Aerial view of laboratory and front of 'A' Building inset*

capable not only of intense loyalty but also of intense hatred, which must have created some difficulties. Peter Trier comments that "Bareford believed in people" and therefore tended to choose his staff on the basis of their personality and all round ability rather than for particular technical expertise. SS Eriks, to whom Bareford reported directly, was in the habit of holding long one-to–one evening sessions with his subordinates and Bareford attended these on a monthly basis; they formed what John Bunton describes as a mutual admiration society, something that was probably no bad thing for the Laboratory. In retrospect though it is unfortunate that Bareford failed to recognise the realities of the structure of the UK Group Board and made no attempt to establish friendly relations with the technical hierarchy ie Mr. Kloppert and Dr. JD Stephenson, Director of Mullard, Mitcham. As we will see this was to have unfortunate consequences, indeed near disaster, for the Laboratory.

In the course of the next two or three years Bareford was joined in Salfords by several of his former Haslemere colleagues and additional staff were transferred to Salfords from the facility in Bournemouth which was then closed. It seems clear that Bareford and most probably Eriks also, saw the task of the Salfords Laboratory as not being simply the generation of know-how and ideas but rather more the realisation of fully engineered specialised electronic systems. To this end he recruited not only scientists and electronic engineers but also designers and draughtsmen and set up a well equipped workshop.

Amongst those who joined the Laboratory from Haslemere were Peter Trier, Norman Goddard, Maurice Kelliher, Bryan Overton and Guy Birkbeck each of whom was to have a major role in the development of the Laboratory. Peter Trier, a brilliant Cambridge mathematician and a most astute man, joined the Laboratory in 1950, he was Director from 1953 to 1969 and more than anyone else was responsible for the Laboratory becoming established as a centre of excellence within the Philips Concern and indeed on the world stage. Chris Bareford had known Peter since the latter joined ASE in 1941, he clearly recognised his qualities and, from the start, saw him as his successor, treating him as his unofficial right-hand man. Norman Goddard an Oxford physicist, thoroughly sound and careful and a microwave systems expert, was Director from 1976 to his retirement in 1984. Maurice Kelliher, an electrical engineer, took a leading part in the linear accelerator work but left the Laboratory for the US in the mid fifties. Bryan Overton was initially concerned with TV circuitry, became a Divisional Head but left the Laboratory in the mid sixties, to manage the Mullard Mitcham factory. Guy Birkbeck, a rather flamboyant individual, led the

design team and subsequently became head of the Engineering Division; he had something of a penchant for flowing curves as is evident from pictures of completed equipment made in the Laboratory at the time. Vic Fry, also ex-ASE, was responsible for the workshop from 1949. Other notable individuals who were present from day one were Cliff Braybrook* and John Palfreeman whilst Eric Snelling and Norman Jackson moved to Salfords from Wandsworth in April 1950. Each of these was to make his career in Salfords and over the years made an enormous contribution to the Laboratory.

Bryan Overton comments that in these early days there was an acceptance of the war-time culture of "making do". In particular office space was in short supply, so too were desks and as a result he and Cliff Braybrook shared a battered table, having an area of less than one square metre, without complaint. No doubt there were other instances of similar hardship.

Although it might seem that Bareford had a difficult task, since the Laboratory had no track record, he was remarkably successful in his prime initial aim which was that of obtaining contracts from the Government Establishments and thereby establishing communication links with them. These contracts included some from AERE Harwell for engineered electron linear accelerators and for a time of flight neutron spectrometer, and

*Senior staff of the Laboratory circa 1947*
*back row from left:* *N.E. Goddard, unknown, A.D. Yorsten, Mr. Keddie, unknown, S. Phillips, C. Dopping Hepenstal, C.H. Braybrook, B.R. Overton, K.O. Ainslie, unknown, Mr. Parker, N. Doherty.*
*front row from left:* *J.H. Richards, Mr. Valentine, E. Jones, C.F. Bareford, M. Kelliher, B.W. Noltingk, G. Birkbeck.*

** Cliff Braybrook had served in the Army during the war, reaching the rank of Major.*

from the Ministry of Supply for several radar systems, which included an elaborate meteorological probe, the Radar Sonde, and millimetric radars. Other Defence contracts included a series of communications receivers (R218/219), having very high frequency stability, and control transmitters for use with guided weapons. Work was also undertaken on transmitters for the BBC and on a system for particle counting and sizing for the National Coal Board. The communications receivers demanded special components, including a high precision tuning capacitor, which were developed in the Laboratory, the design work being undertaken by Stan Phillips (also a former member of ASE Haslemere). Some of these contracts were very large by the standards of the day, the Radar Sonde, for example totalling more than £150,000. The main strands of the Laboratory's programme in the late forties thus included Communications, Radar, Linear Accelerators (perhaps the jewel in the crown), Ultrasonics, Circuit Techniques, Valve Applications (largely focussed on TV receivers) and Components. The work on valve applications undertaken at this time by Emlyn Jones*, Bryan Overton, Ted Emms and their colleagues was of critical importance in establishing the position of the Mullard Company as prime component supplier to the UK set makers. It is probably true to say that the majority of the circuitry used in television sets manufactured in the UK in the first ten years following the post war re-introduction of TV broadcasting was designed in the Laboratory and used Mullard components. Sometimes the group would suggest a novel valve configuration to meet a particular circuit requirement in an optimum way, an example being a double triode pentode which achieved considerable commercial success. All this was a very proper role for industrial research. Television notwithstanding, however, the overall programme could not be described as coherent as the principal determining factor for the initiation of a project was the availability of financial support (mainly external).

Dr. Bareford himself took a keen interest in the linear accelerator programme although Maurice Kelliher was responsible for the work, being ably supported by Tom Chippendale, Bryan Montague (who later joined CERN in Geneva) and design engineers C. Dopping-Hepenstal and David Tremlett. Norman Goddard and Hugh Dell ran the radar systems work while Peter Trier and Ken Ainslie were concerned with communications. Peter Trier was also responsible, with Eric Wolfendale, for the work on the Neutron Spectrometer. Ultrasonics, a Mullard oriented activity, was looked after by Dr. Ben Noltingk (following a brief but unprofitable flirtation with microwaves according to Norman Goddard) and Ernie Neppiras. Valve Applications was the domain of Emlyn Jones and Bryan Overton (and Bryan

* *Prior to joining Mullard, Emlyn Jones and Ted Emms had been employed by Mazda, at that time also a valve manufacturer.*

Montague seems to have had some part) whilst John Richards and Cliff Braybrook were responsible for the work on components, including magnetic items, in which they were assisted by Eric Snelling and Brian Evans. To deal with the radiation hazard associated with the linear accelerators a large pit was dug close to the south west corner of the building and the accelerators were housed and tested within it. Rumour had it that a race of mutated spiders dwelt in the pit.

The highlights of the Laboratory's rather varied work in this early period were probably the Linear Accelerators and the Radar Sonde and a brief discussion of these does not seem out of place.

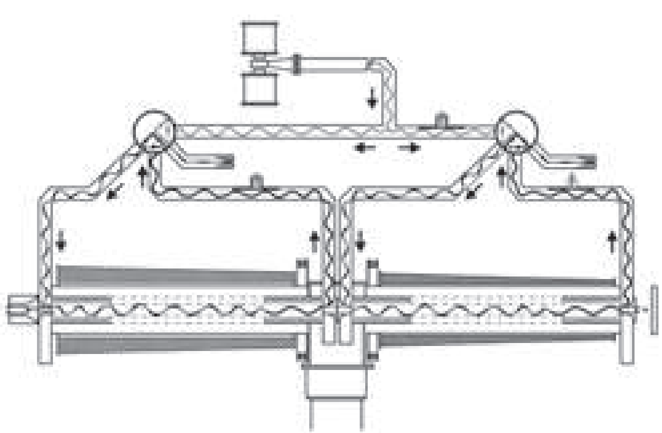
**The Electron Linear Accelerators.**

Work on electron linear accelerators started at MERL with the award of a contract from AERE Harwell for the construction of a 4MeV machine in the late 1940s; this was based on a similar machine developed at Harwell by DW Fry and his co-workers. The success of this contract led to a second, more ambitious, request for the development of a 15MeV machine. This contract was placed in 1950 and the machine was installed at Harwell in September 1952; for a system of such a demanding nature this was something of a *tour de force* and undoubtedly did much to establish the reputation of the Laboratory.

The AERE interest in these multi-MeV electron accelerators was occasioned by the capability of high energy electron pulses of generating short bursts of neutrons for use in time of flight neutron spectroscopy and the greater the energy the better – hence the 15MeV machine. The specification called for 15MeV electron energy with a beam current of 25mA and a length not exceeding 6m, this latter being dictated not by subtle electronic considerations but rather by the dimensions of the installation site. The essential principle of the linear accelerator lies in the interaction of a pulsed electron beam and a high energy travelling electromagnetic wave, the velocity of which is adjusted so that electrons entering the travelling field at the correct phase are continuously accelerated. Energy is thus transferred from the travelling wave to the electrons. The requirements for the structure in which the travelling wave propagates are that it should provide a high axial rf field for a given power input and that the phase velocity should be variable along the length of the structure to keep step with the accelerating beam. A corrugated, or disc loaded, circular waveguide was shown by DW Fry et al of Harwell to be a satisfactory structure for the purpose and was extensively analysed by them. The Mullard design, very sensibly, was based

on the results of this analysis. Although theory indicates that the guide performance improves as the wavelength decreases the availability of suitable power sources dictated that the operating frequency should be 3000 MHz where a 1.8 MW pulsed magnetron was available (the VX4061). This would probably have turned out to be the maximum practical frequency in any case as manufacturing tolerances appear to have been close to the limit and would become even more demanding at higher frequencies.

It is obviously important that the electron pulses do not get out of step with the travelling field and thus phase stability of the field is important and, therefore, so too is the frequency stability of the power source - the magnetron. A notable feature of the Mullard design was that the waveguide structure was split into two sections allowing phase adjustment between them and this significantly relaxed the frequency stability condition. Each of the sections was fed from the same magnetron and was provided with a feedback system so that each section became part of a resonant ring thus further increasing the rf field strength. This was a very practical design and is shown in the diagram.

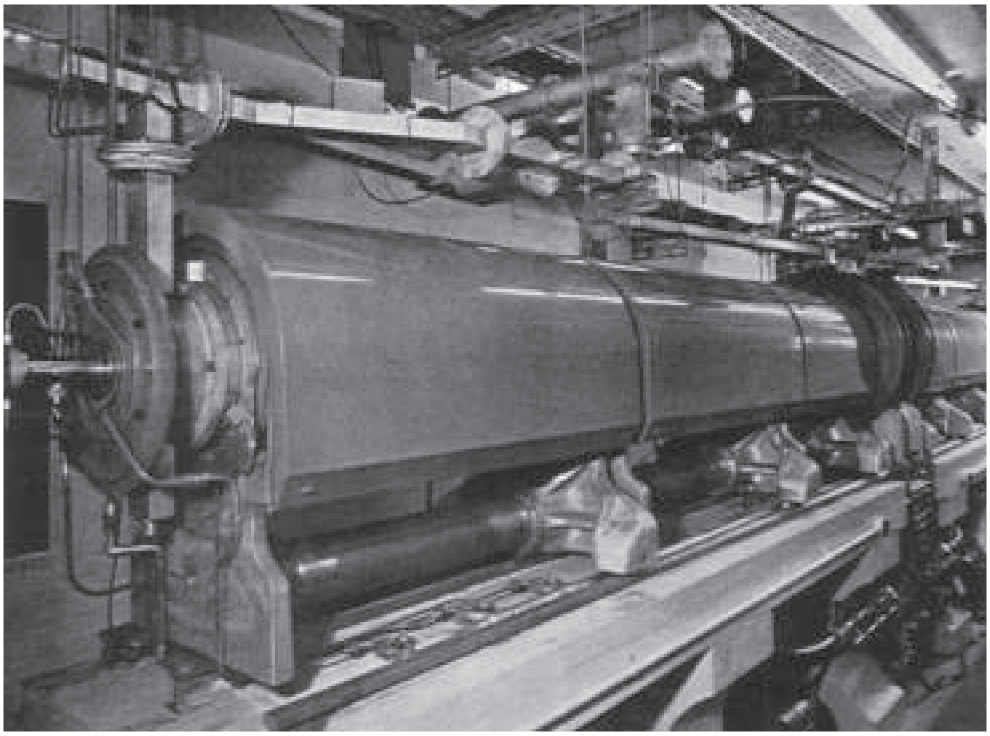


*Linear Accelerator Schematic*

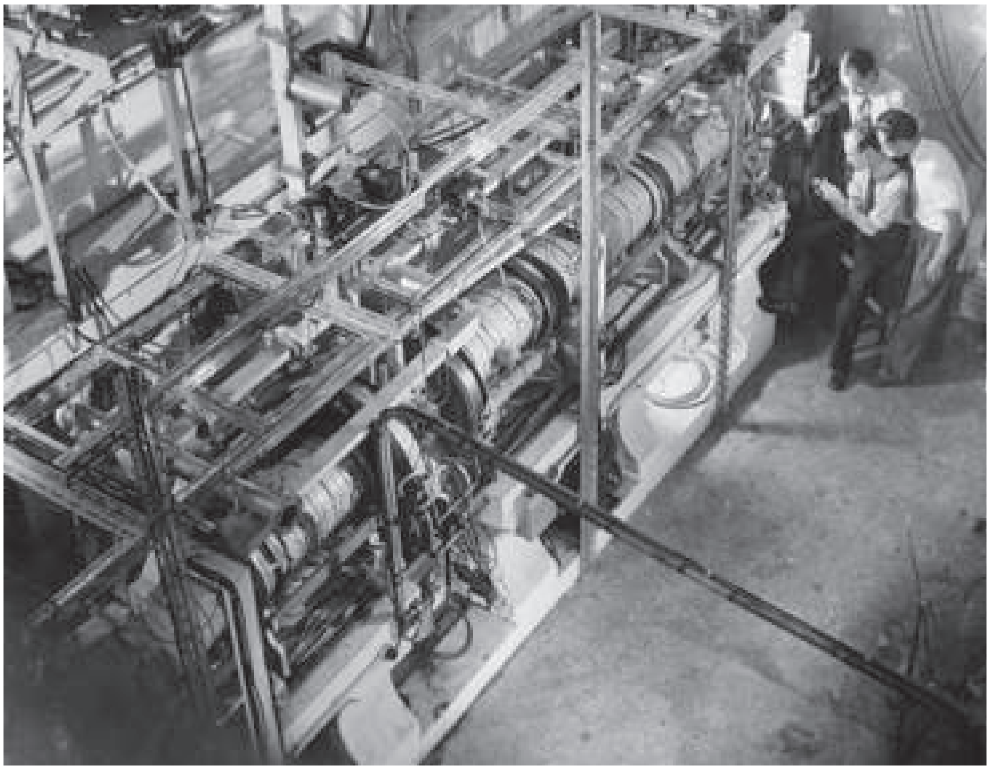
A great deal of effort and ingenuity was devoted to ensuring easy assembly, dismantling and re-assembly of the machine and each of the waveguide sections with its associated parts was divided into three units mounted on three wheeled trolleys running on rails above a massive concrete support. This can be seen in the photograph of the unit at Harwell

When the phases in the feedback loops were optimally adjusted output energies of 14-15MeV were obtained with a beam current of 25mA, 50% of the beam power being concentrated on the target within a circle of 8mm diameter. The maximum X-Ray output from a platinum target was 2250 röntgens/min. and the probability of the most widespread use of such machines being in radiotherapy was duly noted.

The construction of this machine in this time scale was a remarkable achievement by any standards and reflected great credit on all who were involved, some of the team appear in the photograph opposite, which shows the machine being tested in its pit at Salfords.



*Linear Accelarator at Harwell*



*Linear Accelerator in its pit at Salfords, Maurice Kelliher is in the centre*

**The Radar Sonde.**

The radar sonde was a system developed, under contract to the Ministry of Supply, by MERL in conjunction with TRE Malvern and the Meteorological Office for the measurement of wind speed, wind direction, temperature pressure and humidity at heights up to 80,000ft. The system was automatic in operation and provided a continuous record of wind speed and direction as a function of height whilst temperature, pressure and humidity were recorded at approximately 100m intervals of height.

*Radar Sonde airborne unit*

The system consisted of an airborne unit, carried by a hydrogen filled balloon, and a ground station. The airborne unit contained a small combined transmitter and receiver with auxiliary equipment and sensors for measuring temperature, pressure and humidity. Telemetric data allowing the ready determination of these parameters in sequence was transmitted during the ascent at 17sec intervals. The wind vector and height were determined, essentially continuously, by a radar system. This comprised an interrogating signal transmitted from the ground station at 152.5 MHz with a peak power of 50kW and a prf of 404 pps, which when received by the airborne unit, triggered the sending of a pulse (two pulses in fact) at 2850 MHz. The time delay between the departure of the interrogating pulse and the arrival of the secondary pulse provided a direct measure of the range of the balloon; the elevation and azimuth angles of the transmitting aerial, which was automatically kept aligned on the balloon provided the necessary directional information. The reading of each of the three sensors in the airborne unit was encoded once every 17secs into a time delay between the pair of pulses transmitted to the ground for each interrogating pulse received by the unit.

The ground station comprised three major units. The first included the 50kW transmitter and the 10cm receiver together with the ranging and aerial alignment system. The second, the telemetering console, contained the various encoders and recorders. The third was a dedicated analogue computer equipped with a large rotating table and a pen

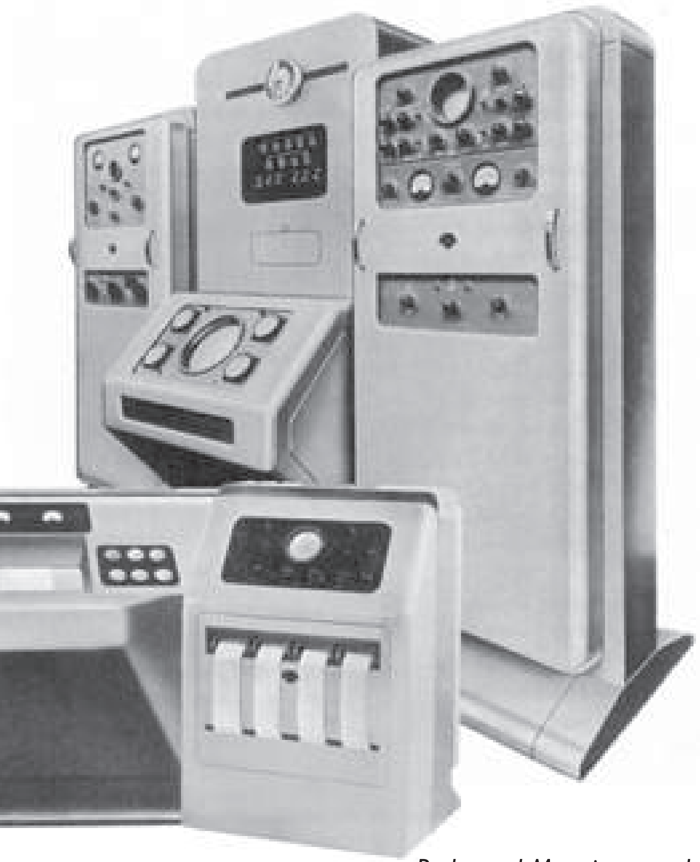
recorder providing a continuous record of wind direction as a function of time during the flight of the balloon.

The system was remarkably successful and it contained a number of features, which, at the time, were very advanced. These related particularly to the sensors, the telemetry system and the automatic signal processing.

From a historical point of view the project is particularly interesting as it provides an excellent illustration both of the nature of the Laboratory's activity at that time and the style of the well-engineered equipment which was very characteristic of MERL.

*Ground Station Aerial*

*Wind computer*



*Radar and Metering consoles*

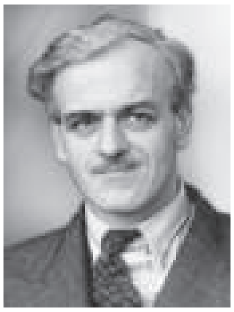
*Members of the Radar Sonde team Left to right: Peter Jago, Hugh Dell,Norman Goddard, Ron Foster*

**The Vacuum Physics Laboratory.**

In 1948 the Mullard production unit returned from Salfords to Mitcham and the decision was taken to transfer the Vacuum Physics Laboratory (VPL) from Mitcham to Salfords. One would like to believe that the prime rationale for this move was to enable the work in VPL on electronic devices and technologies to support and complement the largely systems oriented MERL programme. The historical background, which we have discussed, however, suggests otherwise, and the move was most probably made to enable a reorganisation within the Mitcham plant; we can be pretty sure that achieving a balanced

programme in Salfords was not very high on the agenda of the Mitcham Plant Director, Dr. J Stephenson. What is certainly true is that the VPL Manager continued to report to Dr. Stephenson and regarded Dr. Bareford solely as his landlord. Bareford in his turn continued to report to Eriks and had no direct dealings with Stephenson. The two laboratories were thus managerially independent – a truly bizarre arrangement.

Whatever the rationale, the Vacuum Physics Laboratory duly moved to Salfords and brought with it work on photosensitive devices, gas discharge tubes and microwave tubes together with support facilities in the shape of a well found engineering model shop, a glass technology shop and chemical laboratories. The Manager of VPL was Mr. George Knott, a rugged north countryman and a Cambridge graduate, who, it would appear, was determined to maintain the integrity of his laboratory and its programme and resolutely resisted such attempts as there may have been to rationalise the activities of the two laboratories. In truth there wasn't a great deal of common ground between them but one would have thought that there was merit in seeking to bring the engineering facilities together at least. It did not happen however and the laboratories went their separate ways sharing only the landlord's facilities, the Library, together with the Plant, Accounts, Purchasing, Personnel and Medical departments. The Mitcham emigrés enjoyed certain privileges, in particular a coach was provided, *gratis,* to transport them between Mitcham and Salfords and for several years they were allowed to finish work 30 minutes before the other members of staff, a concession of which they all took full advantage. This did nothing to encourage the establishment of a common esprit de corps.



*Mr. George Knott*

*Mr. James Jenkins*

With regard to the people and the programme, Mr. James A Jenkins, an able and energetic if somewhat abrasive physicist from Glasgow, led the photoelectric work, which included image converters and intensifiers, discrete photocells and exploratory work on the use of semiconductors for infra-red detection. As I recall it Jimmy was always elegantly dressed and more often than not had a rose in his buttonhole. The work in his group on photoconductors, involving preparation and characterisation, was the responsibility of Dr. S Rothschild, an experienced chemist, and the photocell work itself included a pre-production activity run by a Mr. Scott, a stern disciplinarian always immaculately suited. For many years image converters and intensifiers based on the work of this group, in which the leading figures were Jenkins himself together with Bob Chippendale and Alf Woodhead, were important Mullard products largely for application in the military and nuclear

instrumentation spheres. The first of these tubes was the ME 1201, which was developed for use as an extremely fast high speed shutter and was in fact used in MERL in connection with the particle counting and sizing project. The tube was magnetically focussed and, equipped with a separate shutter electrode, enabled exposure times as low as $10^{-7}$ s to be obtained. It earned an excellent reputation in high speed single frame photography and many hundreds were sold. This tube was the forerunner of image intensifiers and infra red image converters and intensifiers which formed a major programme in the Laboratories for many years.

Dr. Norman Robinson, a former member of the Royal Naval Scientific Service, looked after the gas discharge work, in which George Weston took a leading role, in addition Dr. Robinson was concerned with high vacuum equipment. Each of these activities eventually formed the basis of a specialised Mullard product range. Robinson was a somewhat old fashioned empiricist having an intuitive rather than an analytical approach. He had, nonetheless, had several successes and was well regarded. For a while in the early fifties however he was made responsible for a Government funded development programme on wide band travelling wave amplifiers. In no sense was this a good match to his expertise and it was, sensibly, transferred to the third of the VPL groups, that concerned with active microwave devices.

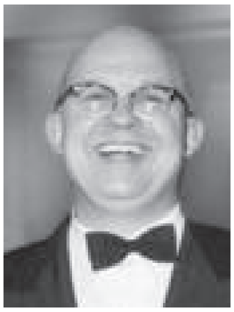
On a personal note, it was to Dr. Robinson's TWT section that I was assigned on joining the Laboratory in October 1952. Other members of this party included Peter Buhlman, an experienced valve engineer,* Harold Hutchinson (Hutch), a very able but phenomenally taciturn mathematician, and Mrs Fenia Berz, an extraordinarily gifted lady and not in the least taciturn, who was employed on a part time basis to study the theory of noise in TWTs. Gordon Kino who became a Professor in Stanford USA and a world figure was an earlier member of this group leaving in 1951. I brought an unprejudiced outlook to travelling wave tubes and microwaves and, having everything to learn, hoped for some help and direction. I found however that it was a matter of finding a niche in the project where one could make a contribution. The tube, with which we were struggling, was a wide band TWT at X-band, the VX 8040. This was being developed under a CVD contract for ASRE (Admiralty Signal and Radar Establishment) and it appeared that there was a need for permanent magnet focussing. A uniform longitudinal magnetic field was considered necessary to confine the electron beam in TWTs and the problem lay not with the magnitude of the field (only 350 oersted) but

*Mrs. Fenia Berz*

* *Peter Buhlman remained at Salfords until his retirement in the 1985.*

with the fact that it was required to extend over the length of the tube ie 30cm. I hit on the idea of using a uniformly magnetised spheroid, within which the demagnetising field is uniform, and accessing that field by means of an axial hole in the spheroid. The scheme worked quite well using Ferroxdure rings, shaped to form an approximate spheroid, and overleaf David Allen and I are pictured testing a VX 8040 in the spheroidal magnet. The negative aspects were that the magnet was extremely heavy, the stray field at its ends was enormous (and very inconvenient) and the noise figure of tubes operating in the magnet was degraded. We only made the one full size magnet and it is perhaps a pity that we didn't go further back in the tube design and consider what sort of electron trajectories were acceptable. Years later Brian Manley and Bernard Murphy did just that and came up with reversed field focussing but that is another story.

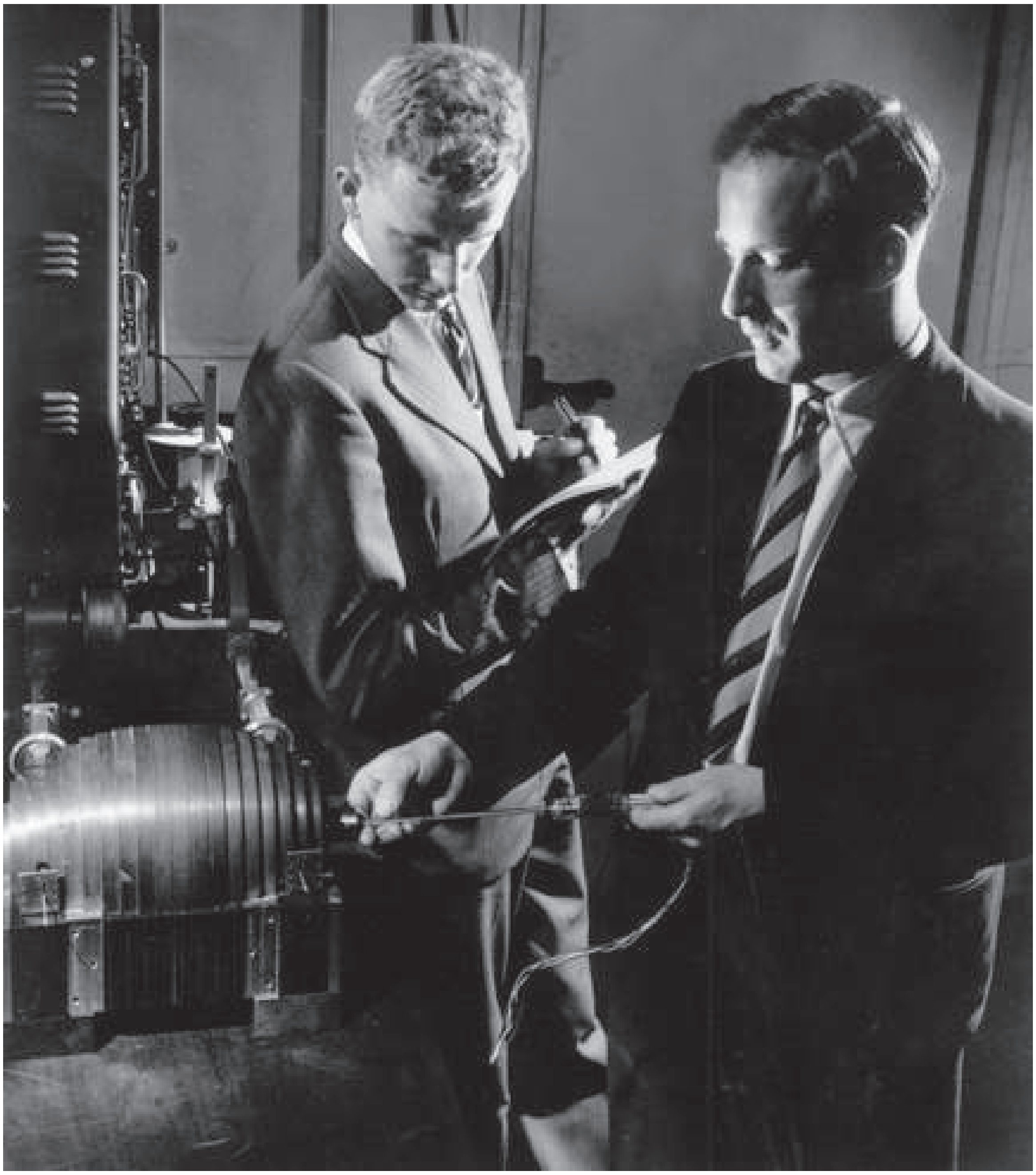
This third of the VPL groups was specifically concerned with microwave tubes and was presided over by Mr. Norman Chanter who had previously been concerned with oil exploration for one of the major oil companies. He was an excellent and astute manager, a loyal Mullard man he was often heard to say "we're Mullard, we make valves". Nevertheless he did not bring much detailed technical direction to the work of his group, this he delegated to several bright and enthusiastic young graduate physicists and engineers who, in the main, had joined the lab after the move to Salfords. Nick King, an ex-naval man, was concerned with magnetrons, Vic Norris, another former naval man, and David Allen, ex-army, with klystrons, David subsequently became responsible for the travelling wave tube work. A team of graduates and technicians supported each of these leading lights. In addition there was Jerry Froom, a slightly older man who had served in the RAF during the war, he was very able and functioned as Chanter's unofficial ADC providing a very sound technical managerial input. This, when joined by the TWT people, was a good and well balanced group and virtually the whole of its work was funded by the Government via DCVD, the Department for the Co-ordination of Valve Development. They made valves.



*Mr. Norman Chanter*

The VPL service facilities included a glass shop, supervised by Harry Flood, a model shop under Frank Champion and a wiring shop run by Mike Stockford and Ron Thomas. There was neither a design nor a drawing office, luxuries for which George Knott had a total disregard. As we have noted earlier, VPL was essentially a self contained unit and, as we will see, continued to operate as such for a considerable period.

One of many curiosities about the VPL set up was that Jenkins and Flood, who was a



*John Walling and David Allen (right) with the Spheroidal Magnet*

brilliant glass technician, owned and ran an independent company based in Sydenham. The main business of this outfit, which was entirely separate from the Mullard Company, was the re-gunning and resale of failed CRTs, in which cathode failure was the most frequent fault. This seemed to be extremely successful, at least it enabled its proprietors to buy and run

identical two tone green Armstrong Siddelely Sapphire motor cars at a time when cars of any sort were not common at the lab and such ostentatious splendour was unheard of. How and why Mullard tolerated this is a mystery; the contracts of employment of us lesser mortals precluded any "moonlighting" activity let alone one that was directly competitive.

**An Uneasy Co-existence.**

The two Laboratories thus pursued their separate ways with very little interaction, due in large part to the insular and uncooperative stance adopted by the VPL Mitcham émigrés who had considerable influence. The increasing number of young scientists and engineers recruited in this period however did not take the same attitude and as their influence grew so the barriers diminished. It is interesting to reflect that the pursuit of common sporting interests, cricket in particular, greatly assisted the process.

In the early fifties Dr. Bareford, probably despairing of any meaningful interaction with VPL, decided to establish a programme on materials, devices and device technology within MERL. He recognised that the future of electronics would depend less on thermionic devices than on the new semiconductor and other solid state devices. Therefore, having received a timely application, he recruited an experienced solid state physicist, Dr. Kurt Hoselitz, to set up a group and to establish a programme on solid state physics and devices. Kurt Hoselitz arrived in Salfords on 1st May 1952 when he was 35. He had studied in Vienna and Bristol, and had established an international reputation in magnetism on which he had written a standard text*. Prior to his Mullard appointment Kurt had been Director of the British Permanent Magnet Research Association in Sheffield, a post which he chose to leave seeking a more progressive activity. His appointment to the Mullard Laboratory turned out to be very shrewd as he had contacts in organisations such as Bell Labs in the USA, Philips in Eindhoven and in the Universities. Hoselitz was well known and well regarded. Indeed, my decision to join the Laboratory in 1952 was indirectly influenced by him as Edmund Stoner, then Professor of Physics in Leeds and the doyen of UK magnetism, with whom I discussed the matter, remarked "I think that must be a good place – Hoselitz has gone there." So I did also.

*Dr. Kurt Hoselitz*

An important factor in Hoselitz's decision to join the Mullard Laboratory would have been the connection with Philips in Eindhoven where some of the best physicists in Europe

* *"Ferromagnetic Properties of Metals and Alloys" Clarendon Press 1952.*

were to be found headed by the great Hendrik Casimir. On Kurt's arrival in Salfords, Bareford, despite not having previously sought much contact with the Dutchmen, lost no time in taking him to Eindhoven. Here he met and became friendly with leading figures in semiconductor physics and transistor technology such as Pieter Haaijman, Frits Stieltjes, Hendrik Klaasens, Leo Tummers and, doubtless, many others. In Salfords though Kurt was, initially, very much on his own in deciding on the nature of programmes of research in semiconductor materials and devices and magnetic materials.

As might have been expected Bareford's decision to initiate solid state work was not greeted with enthusiasm in VPL where Jenkins took the view that such work was his prerogative. It is true that his programme was expanding, with Government support, to include photovoltaic as well as photoconductive infra red detectors together with a significant amount of basic materials work, largely focussed on the lead chalcogenides. In no sense though was this a broadly based programme capable of providing an entrée to the growing field of semiconductor and magnetic devices as it was quite specifically concerned with infra red detectors and materials peculiar to them. Much of this work was highly classified and Jenkins probably felt that this was sufficient reason not to extend the hand of friendship to Hoselitz. It was altogether an unfortunate and unhappy situation.

Towards the end of 1952 Dr. Bareford decided to leave Salfords to take up an appointment as Chief Superintendent of the UK Long Range Weapons Establishment in Woomera Australia. By any standards Bareford's achievement in Salfords was very significant. He had assembled the core staff and established the technological base of a laboratory that was to have continuity of identity and output for well over half a century, being thus well nigh unique in British Electronics. In the light of this it seems most unfortunate that his Woomera appointment was neither particularly successful nor protracted, lasting only long enough for him, in effect, to pilot Black Knight* into the ground (and with it any hopes he might have cherished for a knighthood).

A private dinner party to mark Dr. Bareford's departure took place in the Savoy in early January 1953. This very select occasion is recorded opposite. Those present, going clockwise from the near point (6 o'clock) of the table were:- Mr. Peter Trier, Cdr Hugh Malleson, Manager Mullard Govt. Valve Dept., Mr. FA Kloppert, Dr. Chris Bareford, Mr. SS Eriks, Dr. David Foster, MEL Factory Director, Mr. TE Goldup, Technical Director of the Mullard Company, Mr. Andrew Marner, Commercial Director Mullard Passive Components, (a great friend and supporter of the Laboratory) Mr. George Knott,

* *Black Knight was the name of the largest British long range missile.*

Lt Col Dicky Rankin, MEL Technical Director, and Mr. Christopher Fairfield, the Mullard Company Secretary at the time.

Dr. Bareford's departure from Salfords, although low key and not accompanied by a major farewell celebration in the Laboratory, was, nevertheless, a very significant event and brought to an end this first phase of the development of the Laboratory.

*Private dinner party to mark Dr. Bareford's departure*

# CHAPTER TWO

# THE GREAT DAYS BEGIN 1953 – 1956.

## A NEW MANAGER FOR MERL

At the beginning of 1953 Mr. Peter Trier, at the age of 33, was appointed to succeed Dr. Bareford as Manager of the Mullard Electronic Research Laboratory. Coincidentally the furniture manufacturers, MDS Ltd, had moved to other premises at the end of 1952. The Mullard Laboratories were able to occupy the vacated areas of the building and thus the new manager's appointment was accompanied by a considerable relaxation in the difficult spatial constraints within which the laboratories had had to operate. It seemed a good beginning.

*Mr. Peter Trier*

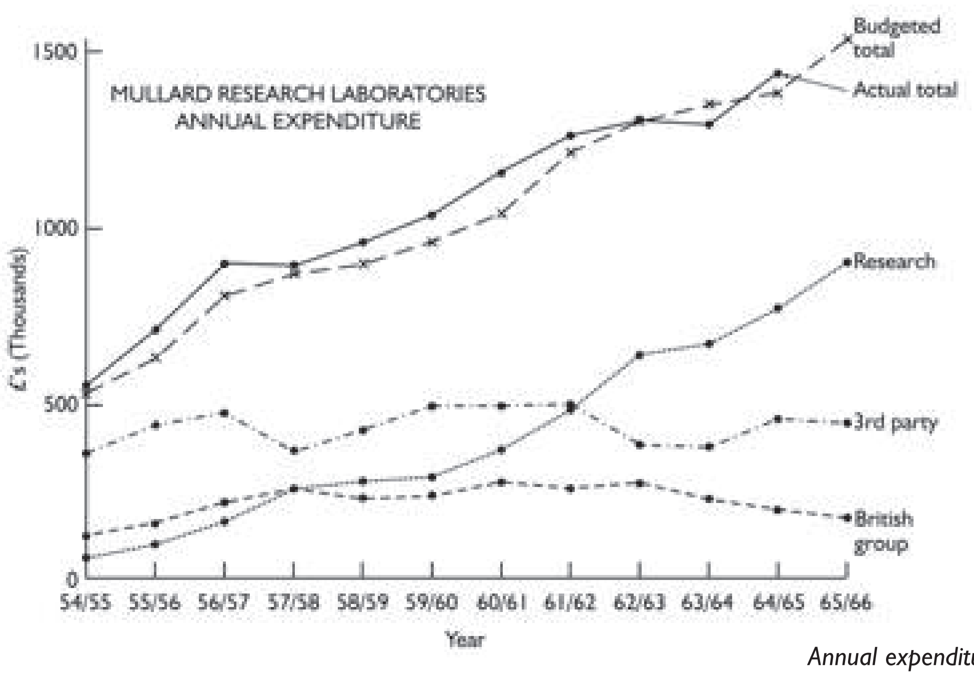
Peter Trier's ultimate long term aim was to build on the foundation prepared by Chris Bareford and to create a broadly based research laboratory of genuine international standing serving the needs not only the of the Mullard Company but, in time, also those of the parent company, Philips. He envisaged a laboratory able to stand beside the Nat Lab in Eindhoven as part of Philips Research. These aims were however not entirely compatible. Research in Philips was traditionally funded by means of a levy on turnover drawn from each of the product groups within the Concern, the Research programme being determined by the Research management in the light of their perception of the needs of the Concern, world trends and their research capability. There was no concept of research or advanced development work being carried out to meet the requirements of third parties, other than in most exceptional circumstances, and the results of the research activity were freely available within the Concern and very often published. As we have noted, however, one of the principal *raisons d'être* of the Mullard Laboratory was that it should strengthen the UK position of Mullard through the obtaining and execution of Government contracts and the consequent interaction with the Government Establishments. Many of these contracts were for specialised devices or systems with

varying degrees of security classification. Thus more often than not the results of the work could not be made freely available within Philips and indeed there were even parts of the Laboratory to which individuals without UK security clearance were denied access. These were alien concepts to Philips and regarded with great suspicion; nevertheless over the years the quality of the work carried out in the Laboratory became recognised within the Concern and the concept of the undertaking of some contract work gained acceptance.

In 1953, when Peter Trier became Manager of MERL and Joint Manager with George Knott of the Salfords Laboratories, however there was no Concern Research funding in Salfords, Dr. Bareford having never sought to establish a Concern identity for the Laboratory. Thus Trier's most pressing immediate task was to secure other financial support for the Laboratory. At that time in the Electronic Research Laboratory 70% of the work was funded from various Government sources, 20% from the Mullard Company for what were largely development programmes and 10% from UK Philips for more speculative work. In Vacuum Physics the situation was similar with an even larger percentage of Government funded work. Thus a large part of Trier's time and effort, and that of several of his senior staff, was devoted to the preparation and presentation of proposals and funding applications. The obtaining of Company support necessitated many visits to Century House (the headquarters of UK Philips, which also accommodated Mullard at that time) for discussions with the Mullard area managers, TH Jones, G Gilbert, JP Jeffcock and A Marner, and with SS Eriks himself for the Philips contribution. Occasionally these exalted individuals (with the exception of Eriks) would visit the Laboratory. I remember George Gilbert particularly, he drove a Bentley (this was before the Company car era) was short, plump, moustached and rather unsmiling. He was responsible for Industrial services in Mullard and I think that the Mullard Government Liaison Officer reported to him in those days, he was thus a pretty important individual to the Laboratory. Certainly the Laboratory Managers went out of their way to be nice to him.

From the outset one of Trier's main aims was to foster relations with the Nat Lab and to agree some funding of the Laboratory with Eindhoven. In this he was urged on by Hoselitz who saw, correctly, that a coherent, first class research programme could not be sustained under the then current hand to mouth funding regime. An important factor in building the relationship with the Nat Lab was participation in the Research Directors' Conference, one of the first of these was held in 1952 and Dr. Bareford and Mr. TE Goldup (Mullard Technical Director) were invited to attend. Peter Trier and George Knott attended

that held in 1954 and Trier and Hoselitz were present in 1956. Peter Trier recalls that the great Nat Lab triumvirate of Casimir, Rinia and Verwey together with a Frenchman, Prof GA Boutry, took part in the 1954 conference. There would have been plenty of opportunity to discuss the Mullard Laboratory and its potential value to the Concern. It would have been at this time that the Dutchmen were beginning to realise that the growth of the Concern would demand research resources beyond those which could be provided in the Netherlands alone. The Mullard Laboratory, which had been built up without cost to Concern Research, was a ready-made active facility having an established capability and an impressive record and it must have appeared rather attractive. Much of the MRL programme was perhaps peripheral to their interests but the expertise and facilities necessary to execute it were not and Casimir realised that an injection of Concern funds would enable a progressive reorientation of the programme towards the Concern. Not a bad investment at all one might think. Thus during the fifties a progressive increase in Concern funding began and with it an increasing acceptance within the Concern of the Mullard Laboratory as part of Philips Research.




*Annual expenditure 1954 - 1965*

Nevertheless within the Mullard Company in the 1950s there was suspicion, even hostility, towards NV Philips. This probably had its origins in the fact that sales to set makers, who were in direct competition with Philips, was a crucial part of the Mullard

business. The Mullard Commercial Departments even tried to project an image of Mullard as an independent firm; Eriks may have passively condoned this and his successor, Dr. FE Jones, appeared sometimes almost to believe it! There were no illusions in the Mullard factories though – they depended on Philips for technology, production methods and machinery on a daily basis. Whatever the cause, though, the dichotomy was very real in parts of Mullard and the balancing of the competing pressures arising from it called for great skill and diplomacy on the part of the Laboratory Manager.

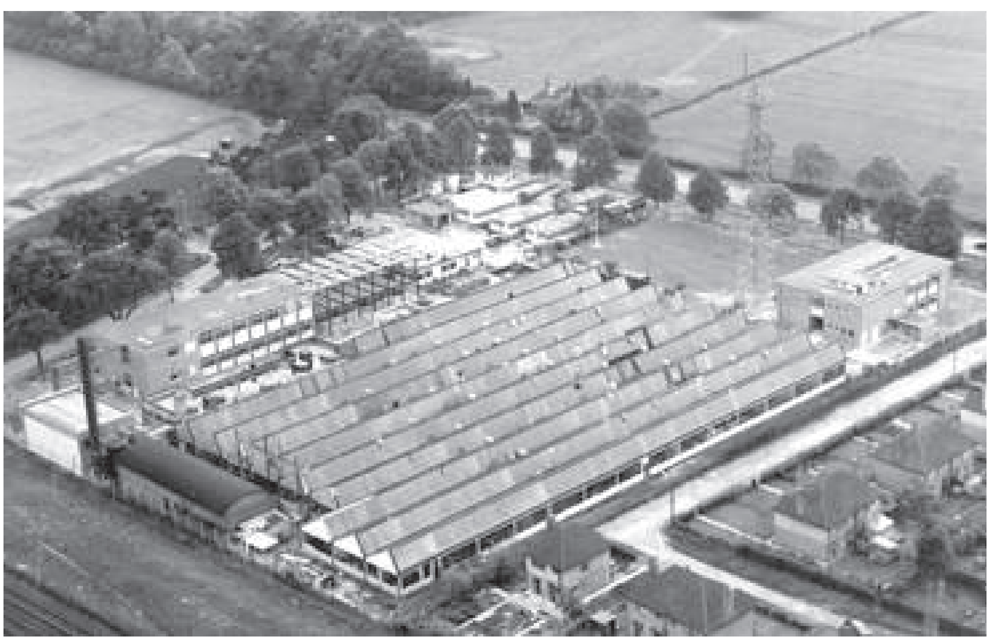
The other major problem confronting Trier on his accession was that of the Vacuum Physics Laboratory which continued to operate essentially independently of MERL on the Salfords site. A number of factors combined to bring about the resolution of the matter. One of these was the Company's decision to establish a Mullard production unit for semiconductor devices in a new factory in Southampton and the appointment of Mr. JA Jenkins as its Director. Thus in 1955/56 a large part of the Jenkins group, together with its programmes of research, many of which were highly classified, moved to Southampton. As this was the area where there had been the greatest tension and difficulty in relations these were considerably relaxed. An even more important factor concerned George Knott, the VPL Manager, who had become personally very preoccupied not with problems of management but with fundamental physics, as he perceived it, and to some extent with cosmology. His consequent neglect of his managerial responsibilities was bad enough in itself but, when he began to seek to involve some of the brighter members of the laboratory staff in his hobbies, the two senior VPL managers felt that they could no longer continue to work under Knott. In the summer of 1955 they took their problem to Peter Trier who, until then had been reluctant to intervene. Realising that there was no alternative and that the matter was urgent he raised it with Mr. Eriks. Eriks in turn consulted Mr. TE Goldup (Technical Director of Mullard) and Dr. JD Stephenson who had regarded themselves, to some extent, as being Knott's protectors. This august trio came to the unanimous agreement that joint management of the Laboratory with two reporting chains was no longer workable (if it ever had been) and that Peter Trier should be appointed manager of the whole Laboratory reporting directly to SS Eriks as Chairman of Philips Electrical Industries. The anomaly of dual management with two reporting chains was thus resolved and George Knott was relieved of his managerial responsibilities*. In 1955 then the way became clear for the integration of the two Laboratories, MERL and VPL, as the Mullard Research Laboratories, MRL, of which Peter Trier was the sole Manager.

* *George Knott was appointed as a Consultant to the Laboratories but this was an uneasy situation, which lasted for barely a year. He left the Laboratories in 1956 and took up a post in Academe.*

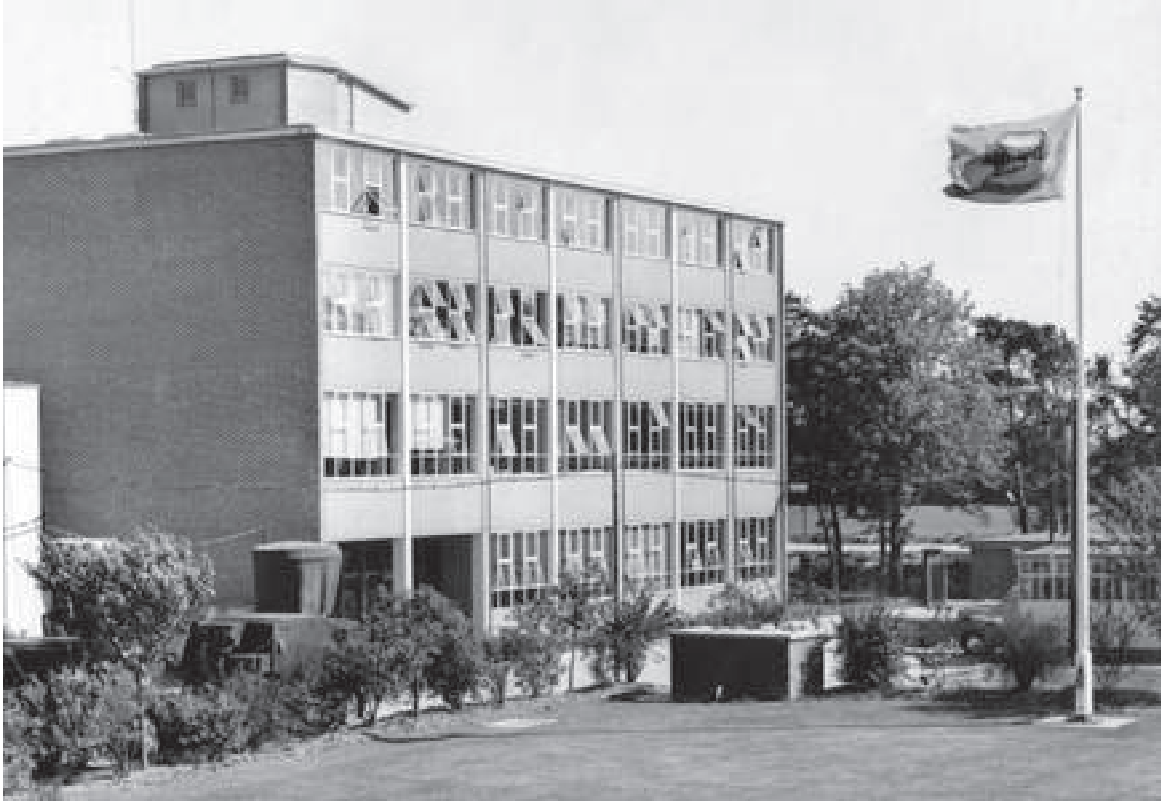
At the same time Mr. Kloppert invited Trier to join the Production Management Committee (PMC) – the monthly meeting of all the UK Philips factory directors. This was an important step forward in gaining internal recognition of the Laboratories as an integral part of the UK Philips industrial activity and in the promotion of an awareness of its activities and staff within the UK Group.

**New Buildings.**

This period was one of great expansion both in the Laboratory numbers and in the programme and the original "A" Building became quite inadequate. In 1954 a new canteen building was completed on open ground between the A23 and the NW corner of "A" Building and a new, two-storey, laboratory building, "B" Building, was constructed to the south of "A" Building, between it and Cross Oak Lane, during 1955. A four-storey addition to "B" Building providing accommodation for the Laboratory Management and Administration departments was completed in 1955/56. The Accounts department occupied the ground floor, the Laboratory Manager's office suite, the Plant Manager's office and Central File the first floor, the Personnel and Purchasing departments the second whilst the Library was housed on the top floor and commanded a wonderful view to the west towards Leith Hill. A new gate house and boiler house completed this mid fifties transformation of the north site.



*Aerial View of development from the North East the new canteen block on the right*



*New 'B' Block*

Obviously the Plant Manager, Ken Caple, and his deputy, John Brunskill, were exceptionally busy during this period of expansion as was also the Maintenance department, headed by Terry O'Donoghue. Ken Caple had been at Balham before the war, had worked for an aircraft manufacturer (Bristol) during the war and re-joined Mullard at Salfords in 1948. He left Salfords to become Principal Personal Assistant to Mr. D van Amstel, who had succeeded Mr. Kloppert as the technical member of the UK Group Board, in the early 1960s. Ken was very much missed in Salfords. John Brunskill, a former Major in the Royal Corps of Signals, who had been Deputy Chief Instructor of the Royal Signals OCTU, had joined the Laboratory in 1952 and became Plant Manager on Ken Caple's departure. Both were extremely capable, largely unflappable and played a very important role in the development of the Laboratory. One could make similar comments about Terry O'Donoghue, the Plant Engineer, a versatile engineer and manager of the old school who ran his department with skill and firmness. He was a great asset and very helpful, despite being occasionally a little intolerant of the sometimes opinionated young graduates with whom he had to deal.

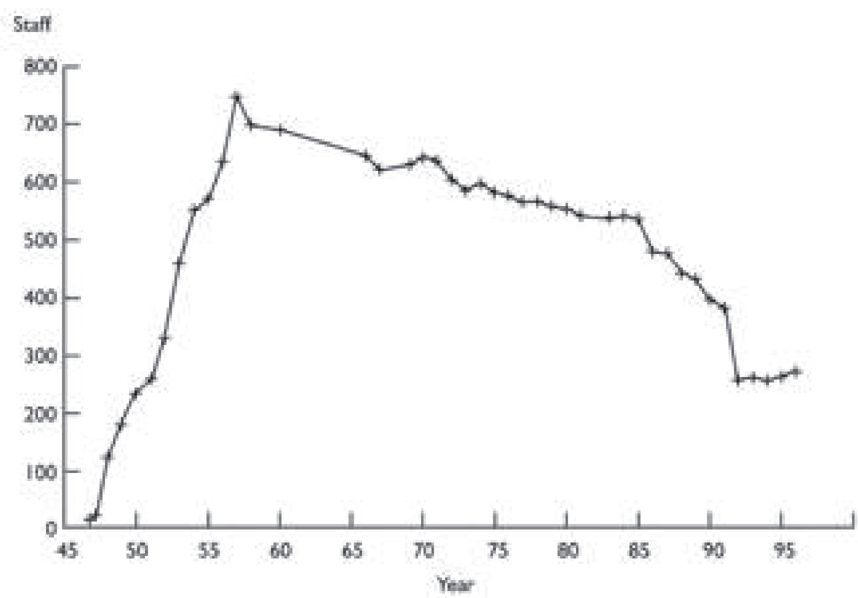
**Organisation.**

During the major part of this period the organisation of the Laboratories remained substantially unchanged with the VPL continuing to operate largely as a separate entity. It was nevertheless a time of enormous expansion in the programme and consequently also in staff numbers which rose from about 350 at the beginning of 1953 to over 700 at the end of 1956.

*Mr. Ken Caple*

Obviously this placed a huge burden on the Personnel Department (nobody thought of referring to people as "human resources" in those days) and they dealt with this, under the direction of the Personnel Manager, George Taylor, remarkably well.

*Mr. John Brunskill*




*Laboratory Staff numbers*

*Mr. Terry O'Donoghue*

*Mr. George Taylor*

## THE PROGRAMME

**The Vacuum Physics Laboratory.**

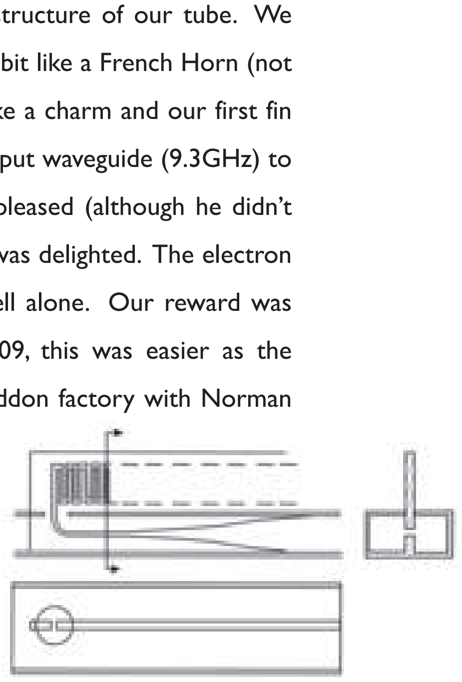
The most important matter though was the development of the programme and we should now look at some aspects of this, starting with the Vacuum Physics Laboratory.

**Microwave Tubes.**

In the VPL Microwave Tubes group there was great activity. Many of us had been profoundly influenced by an IEE lecture given in 1953 by Dr. Robert Warnecke and Dr. Pierre Guénard on the microwave tube work undertaken in the laboratories of CSF (Compagnie Générale de Télégraphie Sans Fil) Paris, who were the world leaders in the field at the time. Mrs Berz was also present at the lecture and it was then that we became even more aware of her value to us, she, we discovered, had worked at CSF and Warnecke, Guenard and company were her friends. CSF were particularly strong in backward wave tubes (which they called Carcinotrons) and they owned the basic patents on these devices*. The backward wave tube is a form of travelling wave tube in which the electron beam interacts with a space harmonic of the travelling field, the phase velocity of which is oppositely directed to the group velocity, the velocity of energy transfer on the propagating structure. There is thus a feedback loop (a series of loops in fact) formed by the structure and the beam and the tube will oscillate at the frequency at which the phase velocity of the backward wave matches the velocity of the beam. It is a subtle and elegant device affording voltage tuning over a very wide frequency range and, following the Warnecke and Guénard lecture, Chanter and Knott instructed the author and EL Lewis (Lyn) to give it some thought. (Lyn Lewis was an exceptionally tall, serious minded, young man whose main interests lay in mountaineering and polar exploration, he nevertheless managed to devote some time to the backward wave tube.) The tube had obvious potential in electronic counter measures and was therefore of interest to the Defence Establishments who were keen to see a UK source of the devices. Chanter and Knott were able to exploit this interest and in no time at all we had a CVD contract. This was not an RP (Research Project), which would have given us an opportunity to get to grips with the basics before essaying an embodiment, but a VX development with a defined specification for a packaged device at the end of it. What ever tale they had told about our capability it could not have been true. A team was assembled, including Arthur Gander a most able and good-humoured Valve Engineer, David Dewdney (a more political individual who moved to the Publicity Dept of Mullard House) and, later, Norman Smith a knowledgeable recruit from GEC, and we set about making tubes. The specification for the VX 8501 called for a tube providing a continuous output of about 50mw from 11GHz to 18GHz – a new frequency range for the Laboratory in which we had no equipment at all. We followed the French and chose an interdigital propagating structure; this consisted of an extended array of interlocking copper

* *Work in the US on backward wave tubes was held back because of an error in John Pierce's classic book "Travelling Wave Tubes", the vade mecum of US tube engineers, indicating that no effective interaction could take place between the beam and a backward wave.*

fingers of rectangular cross section, each about a quarter of the shortest required wavelength long. Such structures will propagate an electromagnetic wave over a wide frequency range, the field distribution being very similar to that of a folded parallel plate transmission line and the largest amplitude space harmonic is backward. The main problems with a device incorporating such a structure were:- firstly, making the structure, secondly, devising a transition from the structure to a conventional transmission system (waveguide) well matched over the whole tuning range, and thirdly persuading a flat electron beam to keep its shape and stay close to the structure throughout the tuning range. The structure had to be completely uniform with no irregularities at all over the active length and here we were remarkably well served by the VPL workshop notably Brian Stephenson and Vic Treasure*, who managed, with great skill, to machine the two interlocking combs (not once only but many times.). The matching system was a big problem as output mismatches caused huge discontinuities in the frequency /voltage and output power characteristics. It nearly wrecked the project but John Winwood, (who had joined the TWT section from English Electric) drew our attention to a then very recent article by JD Robertson describing a propagating system called a fin line. This consisted essentially of a double ridged rectangular waveguide in which the ridges are very thin and separated by a small gap. The field configuration in the structure is very similar to that of a parallel plate transmission line thus offering a route to a folded structure – the interdigital structure of our tube. We adapted Robertson's fin line design for this purpose, it looked a bit like a French Horn (not altogether inappropriately perhaps) but no matter, it worked like a charm and our first fin line tube oscillated continuously from the $H_{01}$ cut-off of the output waveguide (9.3GHz) to about 20GHz. We had won! We were pleased, Chanter was pleased (although he didn't come to see it.) and the Design Authority (DG Kiely of ASRE) was delighted. The electron beam was fairly crude but it was good enough and we left well alone. Our reward was another contract, this time for an X-band BWO, the VX 8509, this was easier as the wavelength was longer and it eventually transferred to the Waddon factory with Norman Chanter. We were then the only people working on the construction of BWOs in the country so the VX8501 was a UK first. Interestingly the fin line, which was our salvation in this project, was rediscovered in the Laboratory, almost thirty years later, in another application by the Systems Division.



*BWO fin line output*

* *Brian Stephenson (Steve) and Vic Treasure each left the lab and set up in business. Steve established a successful domestic appliance business, Keymex, in Reigate and Vic was one of the original directors of Vacuum Generators – a hugely successful major company.*

There were other exciting things going on in the Microwave group. Vic Norris, Graeme Chalk, Tony Bailey and the irrepressible Ken Drummond designed and made a 250kW multi cavity klystron amplifier at X-band. Klystron amplifiers, with suitable drivers offered better frequency stability than magnetrons and therefore became the preferred high power source in many applications including particle accelerators. There was also work on a frequency multiplier klystron driven at S-band with a millimetric output. Nick King and John McKerrow were concerned with a tunable X-band magnetron, which was a superb and very practical device. The important area of travelling wave tubes was the responsibility of David Allen together with, John Winwood, Geoff Steele, Bill Hayward, Jim Beasley, Jerry Froom, Cliff Vince, Peter Buhlman and Harold Hutchinson (Hutch). This team devoted themselves with considerable success to TWTs including low noise devices for the GPO which were to prove of great commercial importance. Brian Manley, who was later joined by Bernard Murphy*, made some notable contributions to the formation and focussing of electron beams, which had been a rather neglected area for us. Among other things, they came up with the idea of Reversed Field focussing of TWTs. This was a compact permanent magnet system, less critical than periodic focussing systems and a lot lighter than coils (or spheroidal magnets.) It was quite widely used and was, in fact, employed by Bell Labs in the 4.17 GHz transmitter aboard Telstar, the first active communications satellite, in 1962. There was some contact with the Nat Lab group concerned with microwave tubes which was run by Dr. PRJA Kleynen, they were always very friendly and helpful and we greatly enjoyed our occasional visits to Eindhoven. We did not have much active co-operation with the Dutchmen though except in connection with a curious device known as the CZ tube (named after its Nat Lab inventors Coeterier and Zijlstra) – a high efficiency microwave oscillator in which CVD were interested at the time.

*Multi-Cavity Klystron Amplifier*

* *Bernard joined the Lab in 1956 (or thereabouts) with a PhD from Leeds. He went to the US, eventually joining Bell Labs where he achieved a very senior position in the organisation. He remains a very good friend of the Laboratory.*

Altogether this was a good and very capable group which had developed considerable *esprit de corps*. This was enhanced by the attendance of six of us (Chanter, Froom, Allen, Norris, King and Walling) at the Congrès International "Tubes Hyperfréquences" in Paris in the summer of 1956. Mrs Berz had made her own way there and none of us will forget her, during a lively discussion, translating a Russian question, addressed to a French lecturer, into French and English and dealing, more than adequately with the reply. She was a truly remarkable lady. Chanter having lectured us very solemnly about the serious purpose of our attendance (of which we were keenly aware) arranged our social programme with conspicuous success, he nevertheless remained "Mr. Chanter" to us. This was the first major international conference that most of us had attended and we had presented three papers, each of which had generated real interest. We felt that we had made a good impression and it was really quite memorable.

**Photoelectrics.**

The Photoelectric Group under JA Jenkins, expanded very considerably during this period and was active in solid state devices generally and in infra-red detection devices and systems in particular. To a large extent their work was undertaken for Government Establishments and was highly classified. Outside the group we knew nothing of the detail of their work and the security available to them was greatly increased when, following completion of the two storey B building in 1954, they moved into it and security guards were stationed at each entrance. Among the 1953 recruits to the group were Max Smollett, an extraordinarily able physicist, relaxed, urbane, something of a gourmet and a fluent French speaker, and Geoff Eaton, also an excellent physicist but, in contrast to Max, always brisk and energetic, seeking to make his mark. Max was Head of Development in Southampton for many years being awarded an OBE in the 1970s and Geoff later moved from Southampton, becoming Director of the factories at Stockport and Blackburn and finally of the UK ISA Organisation. Others who joined the group at this time were Don Morten, Ray King and Robin Jones all of whom established fine reputations in the infra-red field over the years. As we have already noted this Group, apart from the Image Converter section, moved with their programmes to the new Mullard factory on the Millbrook estate in Southampton during 1956, marking the end of an era in Salfords*. One notes with sadness that all of these people have died in the recent past.

*Dr. Max Smollett*

* *The work of this group laid the foundation for the Southampton Infrared dectector programme, which over the years, had a major impact in the military sphere.*

**Gas Discharges.**

The Gas Discharges Group with a new leader CH Tosswill, who joined from AERE Harwell in 1953 continued to concern themselves with Hydrogen Thyratrons and display devices.

VPL's separate existence ended in 1955 and these programmes were thus its last activities. It is noteworthy that virtually the whole of the work was carried out with Government funding and was very successful in that it generated many new product activities for the Mullard Company.

**THE MULLARD ELECTRONIC RESEARCH LABORATORY**

Turning now to the Electronic Research Laboratory, (it was still referred to in those terms) there were no less than nine distinct sections together with the Engineering department reporting directly to the Laboratory Manager, Peter Trier. It must have been very difficult for him. Considerable expansion in numbers took place here as well as in the VPL with the biggest growth being in the Radar and in the Solid State Physics areas. Curiously, in a contemporary document, written by no less an individual than Peter Trier himself, SSP is referred to as "Metal Physics" – it didn't last.

**Solid State Physics: Semiconductors.**

In SSP Hoselitz started work on Germanium point contact transistors following Bell Labs procedures, which had been disclosed to Philips. In this he was assisted by Arthur Jenkinson, who had joined him in 1952, and later by Tom Watkins. Tom Watkins had been one of the Nobel Laureate Dennis Gabor's research students in Imperial College and had been recommended to Hoselitz by Mrs Berz who was also working with Gabor at the time, although in MRL for one or two days per week. Watkins was keenly interested in semiconductor surfaces, which he rightly felt would play a crucial role in the burgeoning semiconductor device technology. Serious surface studies, however, came later as it was first necessary to establish a capability in basic transistor science and technology; in this Jenkinson was rather successful pulling transistor quality germanium crystals and making point contact transistors. He also made devices using a grown p-n junction; Hoselitz believes that these were probably the earliest junction transistors made in the UK. In 1954 a young Cambridge graduate Julian Beale joined the Laboratory, having completed his military service in the REME, and was


*Dr. Tom Watkins*

assigned to the Solid State section. Although he had no previous experience of semiconductors, other than that offered by his degree courses, he rapidly displayed quite remarkable insight and original inventive capability. Amongst his inventions in these early years was that of enhancing the switching speed of germanium diodes by lifetime killing of injected carriers in the base by doping with nickel. This was rapidly taken up in the factories and became a standard process. Another touch of genius was Beale's invention of the alloy diffusion process for the control of the base width in a junction transistor. Previously the emitter and collector dopants had been diffused in from opposite sides of the wafer making the base width very difficult to control. Beale argued, correctly that, as the diffusion rates of dopant species differed, they could be diffused in from an alloy dot, containing the required n and p type dopants, on one surface and that the base width would be determined by the differing diffusion velocities. This too was quickly taken up and the technique was very successful in the production of rf Germanium transistors.

*Mr. Julian Beale*

Hoselitz was rightly convinced that no really useful work could be done on semiconductor materials and devices without control and understanding of the structural and compositional quality of the materials. He therefore established facilities for the growth and purification of crystals and for their chemical, metallurgical and structural analysis in addition to electrical characterisation. John Dale, a metallurgist, recruited at this time, made a speciality of the study of defects, intrinsic and process induced, in semiconductor devices and was to achieve unique eminence in this field within the Concern.

**Solid State Physics: Magnetics.**

The Company's interests in solid state however also included magnetic materials, in particular ferrites, and, whilst a great deal of work had been done in Eindhoven on polycrystalline ceramic materials, some basic questions remained which could best be answered by studies of single crystals. A team was therefore assembled for this purpose; the members included two young PhDs from Leeds, FW (Fred) Harrison and RF (Ron) Pearson together with a Research Technician, John Page, who was concerned with crystal growth. They all joined the Laboratory towards the end of 1954 and, during the following years, achieved rapid

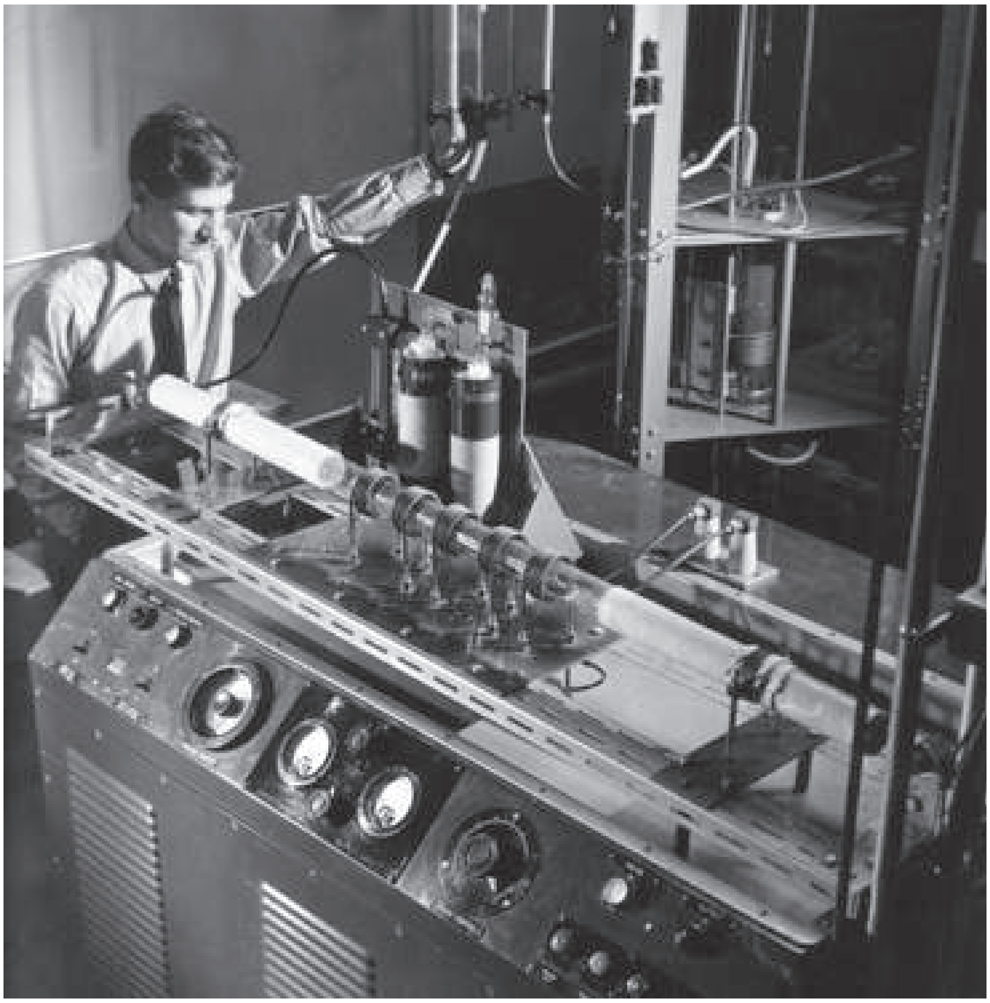
*Dr. Fred Harrison*

*Dr. Ron Pearson*

*John Page and the Crystal Growth Apparatus*

success in the growth of single crystals of ferrite materials. These were initially manganese ferrite and a range of compositions based on it grown by the Verneuil technique. This was a considerable achievement and a world first. It was followed by the growth of other ferrites by the Bridgman technique and of garnets from solution in lead oxide-lead fluoride solvents.

The work subsequently carried out on these single crystals was of the highest quality and did much to establish the Mullard Research Laboratories as a world centre of excellence in this field.

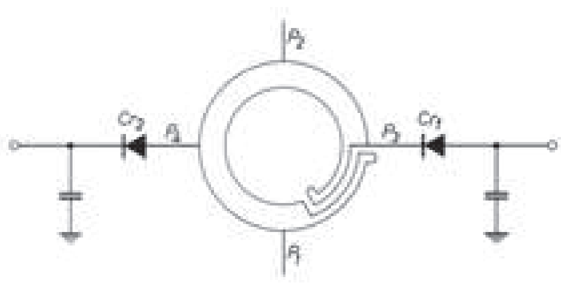


*Arthur Jenkinson with the Zone Refiner*

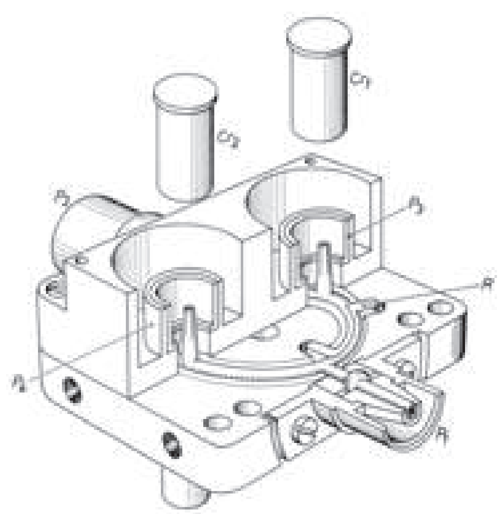
**Radar Systems.**

Elsewhere in the Electronic side there was considerable expansion in the Radar section who were engaged in a number of military radar system developments. Amongst those joining the section in 1954 was SJ (Steve) Robinson a Cambridge Physics graduate who had spent two years in the RAF prior to University. His RAF experience had stimulated an interest in Radar, which was to develop hugely over the years ahead. The fact that several of the Laboratory staff had previously been members of the Admiralty Signal Establishment led naturally to the placing of contracts by ASRE (as ASE had become) for electronic warfare work* and Steve Robinson was employed in this sphere from the start. His first task was concerned with a wide band bearing measurement receiver at S-band for Microwave Electronic Support Measures (ESM) to detect, analyse and counter enemy radar. Interestingly a CSF S-band Carcinotron (BWO) was to be used as the local oscillator in this system and the first such device to be imported into the UK was supplied by ASRE for this purpose (and broken by SJR!). This work was highly classified and although working on backward wave tubes in VPL with the same ASRE people, Tony Hogben and David Kiely, we knew nothing of it. The system called for an S-band balanced mixer having a bandwidth approaching an octave. The bandwidth of coaxial balanced mixers based on the well known "rat-race" is restricted, largely because of the need for one arm of the device to have a length of three quarters of a wavelength, but in 1956 Steve Robinson proposed a brilliant solution to the problem. This was to replace the long arm, in which, at mid band, there was a phase change of $3\pi/2$, by a phase reversal

*Mr. Steve Robinson*



*Sketch of Phase Reversal Ring*



*Coaxial Phase Reversal Balanced Mixer*

* *The need for work on advanced systems for electronic warfare had been greatly increased at the time in consequence of the intensifying Cold War and the Korean conflict.*

coupler which provided a phase change of $-\pi/2$. The performance of the resultant mixer at mid band was identical with that of the basic device but its dependence on frequency was very greatly reduced thus solving the main immediate system problem at a stroke. The construction of the prototype phase reversal hybrid junction demanded very high precision and great skill; Bert Shelton, whose contribution to the realisation of this historic invention was vital, constructed the original devices and many subsequent circuits in the workshop.

This was a quite remarkable invention, the importance of which cannot be overstated; it provided the key to many others and was a basic building brick in a number of major systems the realisation of which would have been completely impossible without it. Some of these will be discussed in the following chapters.

**Linear Accelerators.**

Work on Linear Accelerators went on but with a different emphasis. Whereas the first machines constructed at Salfords were for nuclear research purposes at AERE Harwell, those subsequently realised were, largely, for medical purposes as high energy X-ray sources. 4MeV machines were supplied to the Liverpool and Newcastle Infirmaries whilst a 15MeV machine was developed under the aegis of the Medical Research Council for installation at St Bartholomew's Hospital in London. The work at St Bartholomew's was under the direction of Professor Joseph Rotblat who was awarded the Nobel Peace prize in 1995 and subsequently received a knighthood. These accelerators differed only slightly from those constructed earlier for Harwell and thus did not involve a great deal of design innovation, nevertheless the work entailed by their construction and testing was very substantial and represented a major commitment for the Laboratory. Indeed the successful realisation of these machines was a notable and very creditable achievement for the Laboratory.

**Components and Materials.**

An interesting and major project was carried out in the Special Components and Materials section under a contract placed in 1954 by the RTZ Corporation for an airborne system for the detection of conductive ore deposits. The principle of this system, designated EMU 1, was to generate a large low frequency magnetic field at one wingtip of the carrier aircraft, detect it at the other, backing off the received signal to zero in the absence of any ground conductive anomaly. The aircraft (a De Havilland Otter) was flown

at a height of about sixty feet and the system detected variations in ground conductivity indicating the presence of ore deposits. The project was led by Eric Snelling and involved installation and commissioning in Canada during the winter of 1955/56. It was a considerable success and was followed by a commission to build a bigger and better geo-survey system to be installed in a larger aircraft and operated in Europe. The project perhaps illustrates the preparedness of the Laboratory in those days to undertake specialised one-off activities, which did not contribute directly to the company's product policy, as long as they generated revenue. In this respect it differed markedly from another major project in the same area concerned with the properties and applications of soft ferrites. This work was funded, in the first place, directly by Mullard Ltd (A.Marner), it was an important part of the Laboratory programme for many years and contributed enormously to the success of the Mullard business in this field. One of the outcomes of this work was the publication in 1969 of Eric Snelling's definitive book "Soft Ferrites; Properties and Applications" (Iliffe).

*Mr. Eric Snelling*

**Television.**

Despite the departure of Mr. Emlyn Jones in 1953 when he left to join Dr. Bareford in Australia, the work on Television expanded considerably with a number of notable additions to the staff. These included Graham Cripps, a Cambridge graduate who joined in October 1954 and was to succeed Bryan Overton as Head of the Circuit Physics Division, Richard Jackson, Norman Richards, Tom Jacobs and Ken Freeman each of whom joined in 1956.

**A REFLECTION ON THE FIRST TEN YEARS**

At the end of 1956 the Laboratory completed its first ten years of existence and it is interesting to take stock. The staff numbers totalled 750, or thereabouts, and the total Revenue Expenditure was close to £850,000, of this £150,000 came from Concern Research, £200,000 from the British Group (mainly Mullard) and the remainder, £500,000, from third parties, almost entirely the British Government.

The Laboratory was under the control of a single Manager, Mr. Peter Trier, who reported directly to the UK Philips Group Managing Director, Mr. SS Eriks. The Concern Research Management had a positive awareness of the Mullard Laboratory and was making an increasing contribution to its costs. A new Technical Director, Dr. FE Jones, having an extensive scientific background, had been appointed to the Mullard Board and was taking a

close interest in the Laboratory. Immediately prior to taking up his Mullard appointment FE Jones had been Deputy Director (E) of the Royal Aircraft Establishment (RAE) at Farnborough and previously he had spent several years in the deservedly famous Physics department of the Telecommunications Research Establishment at Malvern.* FE was very knowledgeable and was quick to appreciate the quality and value of the work being undertaken in the Laboratory.

The Laboratory staff had been strengthened by the appointment of a large number of graduate scientists and engineers, these included an émigré Dutchman, Dr. Pieter Schagen, a former member of the Nat Lab staff, who came to Salfords in 1955. He had great experience and expertise in imaging devices and was to contribute enormously to the work of MRL in the years that lay ahead.

World and National opinion was supportive of Science and Technology and few in the Mullard Company questioned the need for a competent UK based research facility. The prospects for the Laboratory, with its enthusiastic, youthful staff, seemed bright indeed as it entered 1957.

* *TRE was later restyled RRE, the Radar Research Establishment and subsequently the Royal Radar Establishment and later still it became RSRE, the Royal Signals and Radar Establishment. It now functions as Qinetiq!.*

## CHAPTER THREE

# THE GREAT DAYS CONTINUE 1957 – 1964.

**ONE LABORATORY DIRECTOR**

As we entered 1957 the prospects for the Laboratory seemed most auspicious. The problems of the Vacuum Physics Laboratory and the two headed management regime had been resolved and MRL was united under a single manager, Peter Trier, who was only 37 but nevertheless one of the older members of the scientific staff.

When the Jenkins group went to Southampton in 1956 they took with them the whole of their activity on solid state devices and infrared detectors and the bulk of the staff who had been concerned with it, those who remained were largely absorbed in the Solid State Group. The work on imaging devices however remained at Salfords and was continued under the outstanding leadership of Dr. Pieter Schagen who, in 1955, had joined MRL from the Nat Lab, where he had worked, among other things, on the Plumbicon. A further exodus took place in 1958 (or thereabouts) when Mr. Norman Chanter together with a large part of the Microwave Tube Group left to set up a new factory for the manufacture of microwave tubes in Waddon. Unlike Jenkins, Chanter left with a very positive opinion of the Laboratory; he had been perfectly happy with the rationalised MRL management and, had he stayed (and lived), he would have been a great strength to it. He was a good boss. Sadly he developed a serious kidney disease and died some three years after his move to Waddon. Microwave tube work, in support of Waddon, continued in Salfords in what became known as the Special Tubes Division. The present author, however, not without much heart searching, left the tube scene and took up a new role in the Solid State area at the beginning of 1957. So too did Mrs Berz, by this time a full time member of the laboratory staff.

During 1957 Peter Trier was appointed to the Board of Directors of the Mullard Radio Valve Company (to give it its full title) and, as a Company Director, he suggested to Mr. Eriks that the title of his main job should be changed from that of Laboratory Manager to

Laboratory Director. Mr. Eriks voiced no objections and so towards the end of 1957 Mr. Peter Trier was appointed as the first Director of the Mullard Research Laboratories. Coincidentally, or perhaps not, he was granted the then very rare privilege of a company car - a blue Rover 90.

**Laboratory Organisation.**

When Peter Trier was appointed as Manager in 1953 nine sections of the Electronic Laboratory reported directly to him. With the addition of the VPL groups the situation eventually became unsustainable and a restructuring was called for. Therefore, round about 1960, the first of the Eastbourne Conferences took place at which Trier and senior members of the Laboratory debated, off site, how best to organise and structure the Laboratory to meet its current and projected future commitments. They decided that a Divisional structure would serve this purpose well and agreed on the following arrangement:-

| | |
|---|---|
| The Solid State Physics Division | Dr. K Hoselitz |
| The Electronics Division | Mr. JH Richards |
| The Special Tubes Division | Mr. DHO Allen |
| The Applications Division | Mr. BR Overton |
| The Telecommunications Division | Mr. RM Godfrey |
| The Engineering Division | Mr. G Birkbeck<br>Mr. KM Caple |

The other support functions, Maintenance (TF O'Donoghue), Purchasing (J Theobald), Personnel (GA Taylor), Administration (FO Munns) and the Library (P Ridgewell) were unaffected by the restructuring and continued as before, some reporting to the Director and others to the Plant Manager – Ken Caple. In the Engineering Division Guy Birkbeck, as Chief Engineer, was responsible for the technical direction whilst Ken Caple was concerned with staff matters, doubtless together with Personnel. In the Scientific Divisions the

scheme, in two cases, SSP and Special Tubes, simply formalised an existing de facto arrangement. In the others though the grouping of activities was new.

This organisational scheme was fairly short lived as, following the transfer of Mr. John Richards to the Mitcham factory, the decision was taken to divide the Electronics Division. Part was combined with the Applications Division to form the Circuit Physics and Applications Division and the remainder joined with the Telecommunications Division as the Systems Division. At the same time the name of the Special Tubes Division was changed to the Vacuum Physics Division reflecting the wider scope of its activities. There were then four scientific divisions viz:-

| | |
|---|---|
| The Solid State Physics Division | Dr. K Hoselitz |
| The Vacuum Physics Division | Mr. DHO Allen |
| The Circuit Physics and Applications Division | Mr. BR Overton |
| The Systems Division | Mr. RM Godfrey |

It was at this time, or thereabouts, that the Vacuum Physics workshop which, for some years had had a separate existence off site, supervised by Ernie Freestone and Bob Taw was combined with the main workshop under the aegis of Vic Fry. The other support functions continued largely unaffected by the restructuring.

The main areas of work undertaken in the Divisions were broadly (there were, of course, changes with time) as follows:-

- SSP: Semiconductor Materials and Physics, Semiconductor Devices, Magnetic Materials and Physics, Chemistry and Low Temperature Physics.
- VPD: Microwave Tubes for Radar and Communications, Imaging and Display Devices, Gas Discharge Devices and High Vacuum Technology.
- CPA: Colour Television, Computers and Storage systems, Magnetic Materials and Components and Applications.
- Systems: Radar, Particle Accelerators, Radio Communications, Instrumentation and Industrial Control.

Work on Ultrasonics, which had been a major activity earlier had evolved in the direction of Acoustic Surface waves and devices, was pursued in the Communications Section, whilst the work on ultrasonic grinding and the like was followed up in the Engineering Division.

In practice this divisional arrangement worked rather well, and remained in place, broadly unchanged, until 1979 when the Vacuum Physics Division was divided between the Solid State and Circuit Physics Divisions as we shall see.

Towards the end of this period Guy Birkbeck, Head of the Engineering Division and a member of the Laboratory since its beginning, accepted the offer of a post outside the Concern; with Newmark Watches. He was succeeded, on an interim basis, by George Taylor, formerly the Personnel Manager, who was then a few years from his retirement. Dr. Alan Ahern, a former member of Solid State Physics Division, who had transferred to the UK Philips Group Personnel Department in 1962, succeeded George Taylor in the Personnel function.

It was also decided that some of the substantial administrative tasks involved in managing the Divisions could better be handled by non-scientific administrators leaving the Divisional heads with more time to devote to the technical and scientific direction of their divisions. After one or two false starts the scheme worked well with Laurie Rogers, a former Naval officer, in SSP, Roger Lamb another retired Naval officer in CPA, John Young in VPD, Ray Perrin, formerly a member of the technical staff in Systems, and Jack Thompson, an extrovert ex-army man in Engineering.

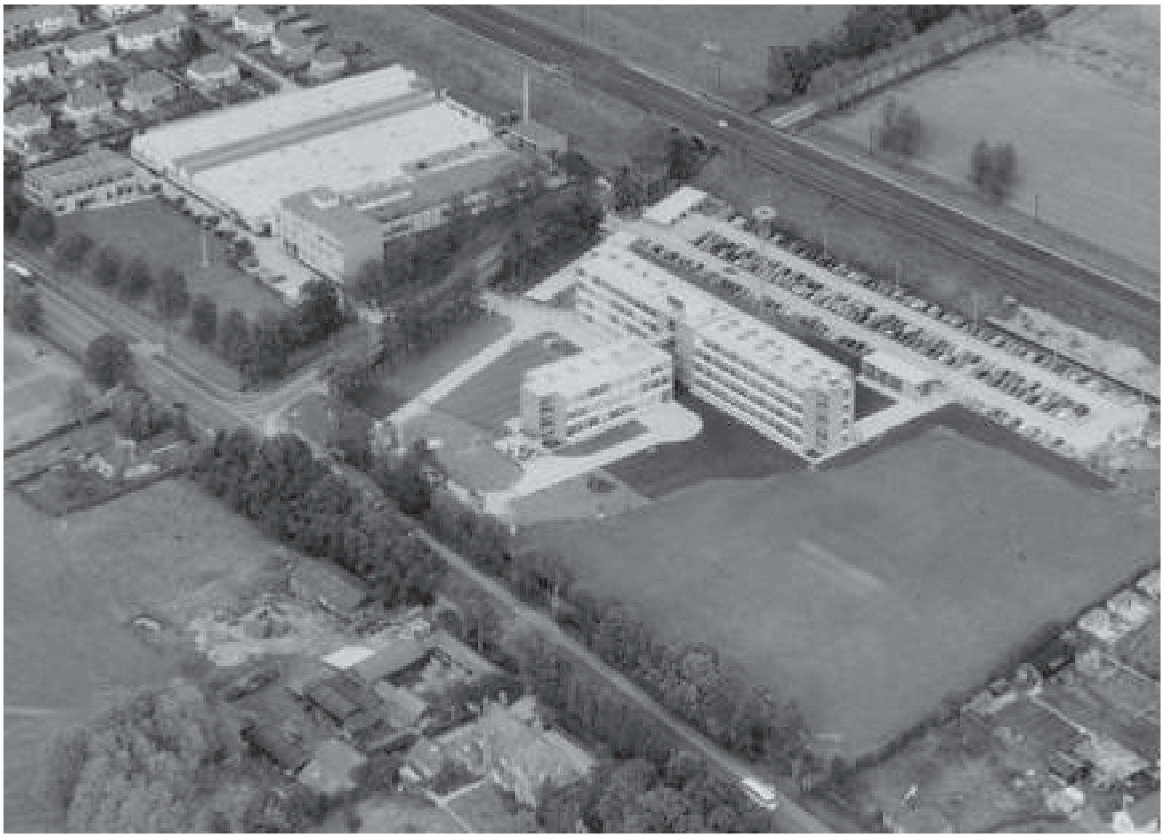
A very significant innovation in 1961 was the acquisition of the first Laboratory computer. This, an Elliott 803, was housed in a dedicated room in "B" block, it had two full time operators, Barbara Vincent (who became Barbara Rudd) and Audrey Hall. A valve machine with a 20kbyte memory it used Elliott Autocode or machine code as its programming languages and ran with five hole punched tape. It was truly wonderful and it enormously enhanced our capability. We wrote our own programmes and were allocated half hour time slots on the machine, sometimes it was booked weeks in advance. Notwithstanding, it seemed (to a frustrated user) to be largely monopolised by the people doing Optical Character Recognition – Tony Weaver and David Woollons, for whose needs it was, in fact, far too small.

**More New Buildings.**

At the beginning of this period the Laboratory was seriously overcrowded as is evident from a photograph of one of Systems Division laboratories taken in 1957 (the young Steve Robinson in the left foreground).

*Systems Division Laboratory*

This situation had been foreseen and, as further development of the North Site had been considered to be impracticable, several acres of land on the south side of Cross Oak Lane had been purchased in 1953/54. This land, however, was scheduled for planning purposes as "Green Belt" and it was some years before permission to develop the site was granted following Government intervention in support of the Company's proposals. The architects, Norman and Dawbarn Ltd who had been responsible for "B" Building, had prepared designs for the new buildings and in 1959/61 "C", "D" and "E" Buildings were constructed by the firm of Higgs and Hill on the south site. "C" and "E" Buildings form a



*South site development*

continuous four-storey block extending in the N-S direction whilst "D" Building, of only three storeys, extends west from the centre of "C" and "E". It is fair to say that the buildings were, and are, rather stark and functional and lacking any architectural distinction. An opportunity lost one might think.

**A Fatal Accident.**

During the early part of this period the Laboratory suffered its only fatal accident. This was to a young service engineer, Mr. Ken Walker, employed by an equipment supplier, who was visiting, by himself, in order to service an ECH machine in SSP. For a very short time he was, inadvertently, left alone in the room with the ECH and in that time he suffered a severe electric shock which proved fatal. Ken Walker was a local man and known personally to several members of staff, indeed his mother-in-law, Mrs Finch, worked in the canteen. It was a very sad and chastening event. I believe that the death was recorded as being accidental.

**Funding of the Laboratory.**

At the beginning of this period in 1957 the Laboratory revenue expenditure was, as can be seen from the figure on page 39, about £900,000 pa but by the end of the year 1964/65 it had risen to £1,450,000 pa. Most significantly the whole of the increase was met by Concern Research and indeed British Group funding fell during the period whilst third party funding, largely Government, remained broadly constant. A very important development which took place in 1959 (or thereabouts) was that Peter Trier reached an agreement with Professor Hendrik Casimir that Concern Research would support the Mullard Laboratory on a guaranteed subtractive basis. That is to say that, whilst MRL would continue to seek external support, in particular from the UK Government, any shortfall would be met by the Concern. Thus for the first time MRL had guaranteed funding and full recognition within Philips as an integral part of the Concern Research organisation. Notwithstanding, the value of Government supported work in MRL to the Concern in facilitating access to markets which would otherwise be closed to it was clear and it was understood, and indeed expected, that the Laboratory would continue to seek such support. The main criterion for undertaking externally supported work however was no longer that of finance but rather that the work should be relevant and potentially useful to the Concern. A very important contribution to the establishment of the Laboratory as a full and integral part of Concern Research was made by Mr. Max Lopes Cardozo who was the first occupant of the post of International Research Co-ordinator (IRC). He had the vision of the research activities in Holland, Great Britain, France, Germany, Belgium and even the USA functioning as a single well-integrated entity and he urged Peter Trier to pursue the Salfords ambitions in this direction. Casimir was never overly concerned about structures and funding but Cardozo saw clearly that for the outlying laboratories like MRL a substantial measure of guaranteed funding was of vital importance; he persuaded Casimir accordingly with the happy outcome we have described. Max Cardozo was a thrusting and sometimes abrasive individual, quite unlike his boss Hendrik Casimir, and not everybody liked him, nevertheless we in Salfords had every cause to be immensely grateful to him.

*Prof. Hendrik Casimir*

*Mr. Max Lopes Cardozo*

*Dr. Hendrik Klaasens*

*Dr. Frits Stieltjes*

A feature of life in the Solid State Physics Division at the time was that the Division was regularly visited by two of the Nat Lab Adjunct Directors, Frits Stieltjes and Hendrik Klaasens. They were always very agreeable and genuinely interested in

the work being done but one had, nevertheless, the feeling of being assessed and monitored. Did we really come up to the Philips standards? It was many years later that I discovered that the other divisions were not subjected to the same scrutiny. Peter Trier remarked that we were indeed under scrutiny for two reasons. One was the fact that the SSP work had more common ground with that of the Nat Lab than had that of the other divisions and the other was that the Dutchmen wanted to see for themselves the work described to them in such glowing terms by Kurt Hoselitz. Whatever, we apparently passed muster.

**THE PROGRAMME**

Although the Divisional structure of the Laboratory which we have described was not in place at the beginning of this period of the Lab's history the grouping is helpful in discussing the work carried out and we shall use it for this purpose. This, perhaps, was the time of greatest activity in the Laboratory and one cannot hope to make mention of everything that was done, rather we will look at some of the highlights and apologise sincerely to those individuals whose achievements and contributions appear to pass unnoticed.

**THE VACUUM PHYSICS DIVISION**

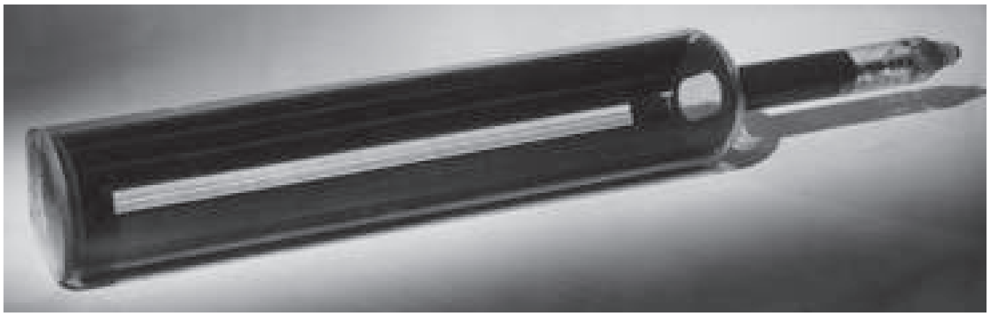
**The Banana Tube.**

This project, carried out jointly between the Vacuum Physics, Circuit Physics and Engineering Divisions and involving co-operation with the Nat Lab and the Mullard factory at Mitcham, was one of the largest to be pursued in MRL. Starting in 1955 in VPD with a small scale investigation it continued until 1961 occupying thirty or more members of the staff at its peak.

The aim of the project was to realise a novel colour television display system different from, but genuinely competitive with, those based on the RCA shadow-mask tube. The shadow-mask tube had been developed over many years; it was the subject of a comprehensive patent portfolio and one of the main underlying objects of the Banana tube project was the generation of competitive patents in same area. Apart from the patent situation the shadow-mask tube was of forbidding technical complexity, difficult to make and set up and very bulky. The search for a simpler, cheaper, alternative was therefore a legitimate, indeed a compelling research objective for Philips.

In principle the banana tube was of beguiling simplicity. It consisted of a cylindrical glass

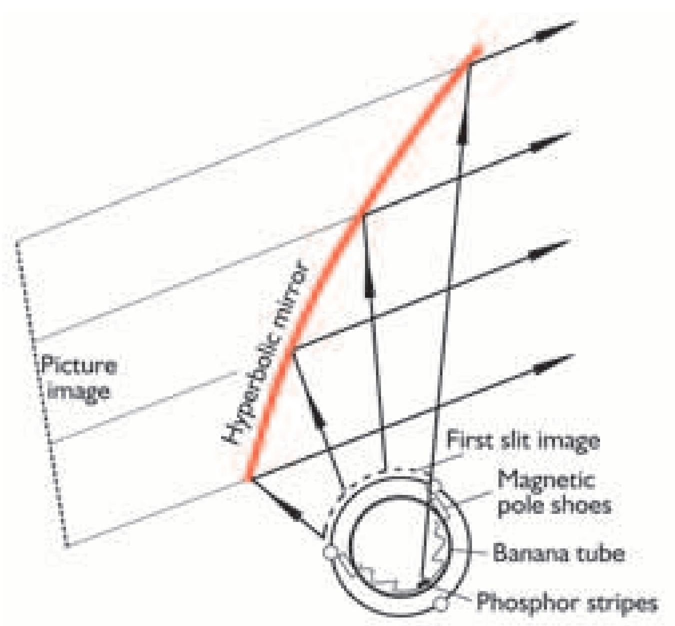
tube containing three thin, parallel, phosphor stripes extending along the length of the tube; an electron beam was scanned repetitively along the length of the strip using normal line deflection methods, colour information being imparted by a spot wobble technique. To improve the spot shape, which became very elongated with increasing distance from the electron gun, a tapered magnetic field was applied in a plane perpendicular to that of the electron trajectory. Further improvements resulted from depositing the composite phosphor stripe on a metal substrate, mounted on a corrugated screen carrier within the tube, and coating the inside of the tube with conductive tin oxide to avoid charging effects. The resultant tube is shown below, the simplicity of the configuration being undeniable.



*Banna tube*

A picture image was generated by using a circular cylindrical lens to produce a virtual image of the line and scanning that image in a more or less vertical plane by means of an opto-mechanical system. This most ingenious arrangement consisted of three identical cylindrical lenses mounted in exact 120° symmetry on a cylindrical metal drum rotating about an axis coincident with that of the tube itself. The image of the phosphor stripe produced by the cylindrical lens was demagnified in the vertical plane by a factor of five but, of course, its extension in the horizontal plane was that of the original phosphor stripe. The use of a hyperbolic cylindrical mirror positioned with respect to the tube and the lens drum as shown overleaf, enabled the generation of a virtual picture image in a near vertical plane behind the mirror.

Although the concept of the system was not difficult, its realisation presented many problems. With regard to the tube itself the choice of phosphors was dictated by a short fluorescence lifetime as afterglow effects produced unacceptable, vertical coloured streaks on the picture. Only sulphide phosphors could be used and these did not completely conform to the NTSC colorimetry requirements (this was before the emergence of the PAL system). Small spot size and high brightness requirements called for high beam voltage and current (25kV and 500μA) which gave rise to problems with the life of both the cathode




*Picture formation in the Banana tube system*

and the phosphors. The beam trajectory and hence colour performance were also very susceptible to external magnetic fields (even the earth's field was important, requiring compensation). The cylindrical lenses, consisting of liquid filled high precision glass tubes, were very precisely located on the lens drum and they, and their mountings, were required to withstand the centrifugal stresses resulting from the rotation of the drum. The drum itself, closed at the end on which the drive motor was mounted, was open at the other to permit insertion of the tube; the open end being supported by a symmetrical arrangement of rollers. The design and evaluation of the components of this mechanical system to ensure reliability and minimum vibration and noise over an extended period called for a long and painstaking investigation led by Harry Howden in the Engineering Division. The special circuits required for the operation of the banana tube display were many and sophisticated and included circuits for spot wobble modulation, lens drum synchronisation and control and video signal processing in the NTSC system. The circuit work and the colorimetry work were carried out in the Circuit Physics area under the aegis of Ken Freeman and Richard Jackson respectively. The people involved with the tube work were Pieter Schagen, Bernard Eastwell, Nigel Calder and Denis Cox. The Banana Tube project was pursued in MRL at the same time as a related activity in the Nat Lab, the Mallet tube led by Dr. Eddie de Haan, and there was close interaction between the two groups.

Notwithstanding the difficulties, banana tube displays were realised and demonstrated both within the Concern and externally. Opposite we see a party of distinguished visitors to the Laboratory in 1961 being shown a complete working system. In May 1961 the display was the subject of a working demonstration and a series of papers presented at the IEE which won the Blumlein-Brown-Willans Premium.

The display system had a number of positive features the most notable being its

insensitivity to ambient illumination, its compact, relatively flat, geometry and the simplicity of the tube construction. Against that had to be set its limited viewing angle, difficulty of setting up, instability of operation, the noise, vibration and fallibility (however small) of the mechanical scanning system and the short life of the tube. In the light of these considerations a Concern decision was made in 1961 not to take the system into development. The project was nevertheless an entirely proper subject for research and successful in that the completion of a fully working system provided the information on which a sound commercial decision could be based in an area crucial to the Concern's interests.

Of the principal players in this drama Pieter Schagen, Ken Freeman, Richard Jackson, Denis Cox and Harry Howden remained at the Laboratory, Nigel Calder joined the staff of the "New Scientist", and later the BBC, whilst Bernard Eastwell left in 1961 to set up his own company, the hugely successful "Vacuum Generators".

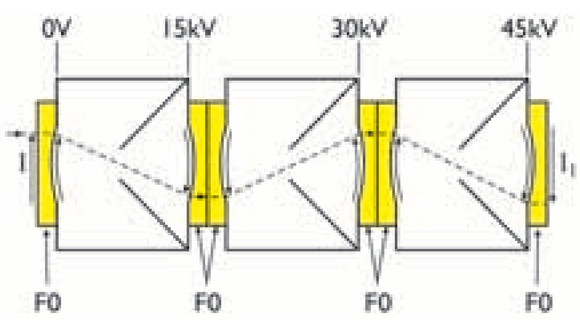
*Lord Thorneycroft and Dr. FE Jones look at the display with Bernard Eastwell, Peter Trier, Ken Freeman and Pieter Schagen*

**Night Vision.**

A major activity in the Vacuum Physics Division, which was initiated during this period, was concerned with what was then a novel approach to military night vision systems. All parts of the armed services were obviously interested in being able to see in the dark and the systems existing at that time depended on the illumination of targets by an infra-red searchlight and their observation using an image converter system. A huge disadvantage of these systems was that the searchlight, whilst invisible to the naked eye, shone like a beacon to a potential enemy equipped with a suitable IR detector.

Pieter Schagen suggested an alternative approach which was to make use of the residual night sky radiation rather than a searchlight. He argued that a dark adapted observer viewing a low brightness phosphor screen of a simple image intensifier, having an appropriate photocathode, would be the most sensitive viewing system. The Military Establishment was sufficiently intrigued to place a number of highly classified contracts for the development and evaluation of systems based on this concept. Several suitable image intensifiers were made in the Laboratory and tested under various field conditions. These devices called for large aperture reflective objectives eg 300mm diameter at f/0.76, which were made by a specialist contractor. The systems were tested at night in the Ashdown Forest in Sussex and subsequently at sea in co-operation with the Royal Navy. On one such occasion a lighted cigarette was observed on the deck of a blacked out frigate some two miles distant. The basic validity of the concept was convincingly established but the need for the observer to be fully dark adapted, a process requiring at least 20 minutes, even for a willing and co-operative individual, was a serious practical drawback.

An alternative approach was to employ a much higher gain image intensifier system to present a high brightness picture to the viewer. This became practicable with the availability of fibre optic plates which could be used to couple several electrostatic image converters as shown on the left.




*Fibre optic coupling of image intensifier tubes*

A practical system then consisted of the objective optics, three fibre optic coupled intensifiers and an eyepiece or camera tube. In the design of

these systems, particularly the objective, the modulation transfer function (MTF) of the various components was used as a prime design parameter in preference to the more traditional resolving power. The MTF describes the response of an instrument to sinusoidal input patterns of varying frequency and the overall response of a complete system can be found by multiplying the functions for the individual components. The use of the MTF proved to be a very powerful design technique and for a while the Mullard Laboratory possessed the only facility in the UK for the measurement of this characteristic of an optical system or component; it is sometimes referred to as the contrast transfer function.

The higher brightness afforded by these systems eliminated the need for dark adaptation of the observer and made viewing of the image much easier. It did not, however, provide any information additional to that available from the low brightness, single stage system and the resultant final device was somewhat cumbersome.

A more elegant and practical solution to the brightness problem in night vision systems was afforded through the use of channel plate multipliers to amplify the electron current emitted by the photocathode. The channel electron multiplier formed an important part of the VPD programme for many years and it is discussed in more detail in the next chapter. In the night vision application a micro channel plate some 30mm in diameter, comprising a stack of channel tubes each of diameter 25μm was incorporated into the image tube giving some 60dB amplification of the photocurrent and a consequent increase in the image brightness. The channel plate however brought with it a range of new problems concerned with the fabrication of plates providing the necessary resolution and outgassing contamination resulting from the very large surface area within the tube. The gaseous contaminants gave rise to energetic positive ions which bombarded the photocathode with disastrous consequences for its life. To avoid the latter effect it was necessary to tilt the axis of the channel plate, a delightfully simple solution which was duly patented in 1963. Some twenty-four years later this patent became the subject of a legal action in which the US Philips Corporation sued the US Government for $50 Million for infringement by one of its contractors, Varo. The infringement was clear but it seems that the matter was settled out of court for a substantial sum but for how much we do not know. Brian Manley, the principal inventor, enquired as to what proportion would be his but was reminded that he (as we all did) had assigned his rights in the patent to Philips at the time of filing in the US for the sum of $1.

There were many difficult problems associated with the introduction of the channel

plate multipliers to these night vision devices but all were tackled systematically and solved in time with the result that the military were supplied with a number of very advanced systems for night vision. These included, for the first time, night vision goggles, which were widely adopted and remain in use today for military and civilian surveillance.

This activity formed an important part of the Laboratory's work for many years and the principal participants were Pieter Schagen, Alf Woodhead, Daphne Lamport, Brian Manley, Don Taylor and John Adams ably supported by members of the Engineering Division and the Glass shop.

**Microwave Tubes.**

The Division continued to work on microwave tubes during this period. A particularly successful exercise was the development of a 6GHz Travelling Wave Tube for communications, the LB6-20, which enabled Mullard to obtain an *initial* order from RCA for Western Union Telegraph worth \$2M. The tube was used in a US coast to coast link and Mullard obtained this order in competition with twelve other leading companies, which provides a good indication of the technical excellence of the tube. Nick King was responsible for this tube and also for an interdigital magnetron for use in microwave cookers, also a most valuable contribution to the Mullard microwave product range. Nick read a paper on this device at the 1960 International Tube Conference in Munich and his excellent practical presentation followed a rather abstruse theoretical paper on magnetrons by Peter Lindsay of GEC (Peter later became a Professor at King's College). Nick felt somewhat discomfited by this juxtaposition but he had no need to do so.

MULLARD'S \$2M. ORDER

VALVES FOR U.S. RADIO SYSTEM

By Our Radio Correspondent

A \$2m. contract to supply a special type of valve for an American coast-to-coast radio communications system has been won by Mullard.

The Radio Corporation of America has ordered travelling wave tubes, which are a type of electronic valve for amplification of frequencies beyond those at which an ordinary valve can function successfully.

The tubes were developed by Mullard's Research Laboratories, and will be manufactured at its microwave valve plant at Waddon, in Surrey. First deliveries are scheduled for May next year.

*Press cutting*

**THE CIRCUIT PHYSICS DIVISION**

Probably the largest of this Division's activities during this period was the work on the Banana Tube Display system. There were also substantial programmes in computer storage systems including those based on ferrite cores, magnetic thin films and superconducting elements. However as the bulk of the work in these fields, particularly that on magnetic thin films was carried out in the Laboratory later on it will be discussed subsequently.

**Television.**

Apart from the Banana Tube, there was a great deal of work directed at the use of transistors in television sets. Bryan Overton read an epoch making paper on the subject to the Television Society in April 1958 and an all transistor TV set was demonstrated at the IEE in the same year. At least it was almost an all transistor set, although it had a conventional picture tube and a small valve in the EHT supply. There were also some pioneering experiments on colour television using displays based on three CRTs. A complete working system was in fact made for demonstration at one of the Radio Shows but, for some reason, it was not shown publicly but only demonstrated within the company.

**Automotives.**

In 1962 an entirely new area of transistor applications work was started with a view to developing a new market for the Company's products – this was that of automotive research. The principal participants were Derek Skoyles, Russell Wynn (a relative of Godfrey Wynn, a well known broadcaster at that time) and Dick Lindop. The main areas of work were in electronic ignition systems, antilock braking and automatic transmission systems. Antilock braking systems, a feature of the Laboratory's programme for many years, were Derek Skoyles' particular forte; in the early days he collaborated with Rod Dale, then a rising star in the Engineering Division, who sadly died, very prematurely, in the early sixties. The transmission system concept pursued was that of converting a conventional manual gearbox and clutch into an electronically controlled automatic transmission. In this system hydraulic actuators, controlling the gear shift and clutch, moved in response to signals from a control circuit regarding, *inter alia,* road speed, engine speed, throttle and clutch positions and the state of the actuators. It was hoped to realise a viable system capable of being manufactured at a much lower cost than that of existing automatic transmissions and indeed a working prototype was made. No doubt intensive efforts were made to interest the car manufacturers in developing the system but it would seem that these were not successful. Amazingly, prototypes of both ABS and Automatic transmission systems were initially tested in the Laboratory's staff car park, which during working hours tended (not surprisingly) to be occupied by cars owned by members of staff. The predictable result was that, on one occasion, a system failure (I don't know which) resulted in damage to several of these cars. I cannot imagine that the conservative John Brunskill, then Laboratory Manager, would have willingly agreed to these experiments!

## THE SOLID STATE PHYSICS DIVISION

**Low Temperatures.**

During the mid-fifties there was a growing realisation amongst the solid state people in the Laboratory that the work on the characterisation of semiconductors and magnetic materials could be greatly furthered by experiments made at low temperatures, there was also an interest in superconductivity. It was therefore decided to set up the necessary facilities for low temperature work and I, having had some experience in this sphere, was invited to do so. I didn't exactly jump at it because I was happy in microwave tubes but it was a challenge and I thought that there might be some opportunities for synergy between the disciplines, and so in the beginning of 1957 I moved. I joined the Solid State Physics Division in the part of B Block vacated as a result of the move of the Jenkins group to Southampton. The transition from the rather formal environment of VPL to SSP where the management style was relaxed in the extreme was a colossal culture shock but I will leave it at that. My new colleagues in the section were:- Dr. Alan Ahern, a Sheffield graduate who was to achieve great eminence in the UK Philips Group in the Personnel Function, Ted Hentley, who was, at the time, a Technical Assistant but became a Mullard Commercial Manager, and Ron Pratt an exceptional experimental physicist, formerly with the Jenkins Group, who was to have a crucial part with Brian Ridley in the demonstration of phenomena related to the Transferred Electron effect. Later in the year we were joined by Peter Bunn, who had previously worked at RRE Malvern with Dr. David Parkinson, and had extensive experience of low temperature techniques. Later to become Head of the Engineering Division, Peter was a priceless asset and a great colleague. Harold Hutchinson joined us from VPD in 1958, after a long illness*, and the section was further strengthened in that same year by the recruitment of David Paxman and Peter Gould.

*Mr. Peter Bunn*

*Mr. Harold Hutchinson*

Liquid helium and liquid hydrogen were the vital fluids of low temperature physics. Neither was commonplace but the National Physical Laboratory at Teddington, having recently purchased an Arthur D Little Collins Helium Liquefier, had surplus supplies which they proposed to make available to outside customers at £5 per litre. This scheme was called the NPL Liquid Helium Pool and we joined, the only condition (apart from paying the bill) being that the evaporated helium gas would be collected, compressed into cylinders and returned. Fines were imposed for shortfall and impurity as helium was rare in those days. Our first delivery from the NPL was on a sunny evening in September 1957. Kurt Hoselitz

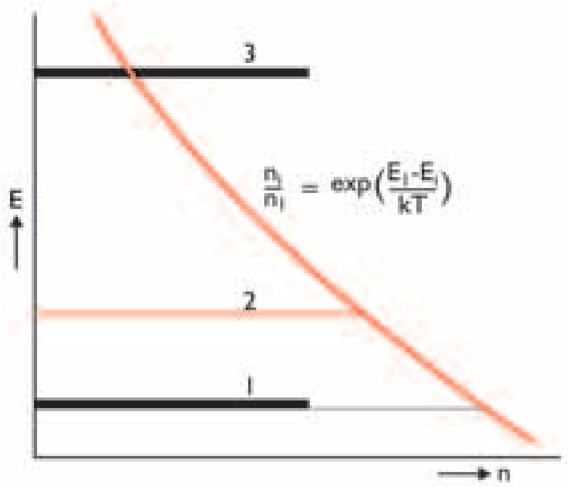
* *To our qreat regret Hutch died suddenly in 1963*

and I had stayed late to welcome it and we did a quick experiment demonstrating the Meissner effect to ourselves by "floating" a small permanent magnet in a lead bowl (which we had prepared earlier) cooled to below its superconducting transition temperature in the liquid helium. It was heady stuff, if not very serious. However, liquid helium could be difficult and expensive to handle and wasn't necessary for intermediate temperature ranges (12K upwards), Peter Bunn and I therefore designed a hydrogen liquefier. This machine, of a rather sophisticated design, was built, for reasons of expediency, in the VPL workshop, which at that time had a separate existence, off-site and about half a mile to the north. When complete the machine was housed initially, for safety reasons, in "the barn" on the railway side of A block. It worked very well and it was later moved to a purpose built separate facility on the South site, adjacent to E-block where it was joined in April 1961 by our own Collins helium liquefier. The liquefier building was, in fact, the first of the South site buildings to be occupied. Having acquired the Collins we had no further need to buy in liquid helium supplies but the NPL, and later BOC, had served us well.

**Solid State Masers – MRL and Telstar.**

In 1956 Nicolas Bloembergen, a Dutchman, at that time at Harvard, published a proposal for a new type of microwave amplifier exploiting electron spin resonance in a paramagnetic crystal. The ground state energy levels of a magnetic ion in such a crystal can be split by the combined action of the crystal field and an external magnetic field; transitions between a pair of these levels can be stimulated by an rf electromagnetic field satisfying the Einstein relationship ($hf = \Delta E$). Upward transitions take place with absorption of energy from the rf field and downward transitions occur with emission of energy. The emitted radiation is in phase with the original stimulating field and therefore adds to it; however, since the number of upward transitions normally exceeds the number of downward transitions a net *absorption* of energy is observed. This is paramagnetic resonance absorption, a well-known phenomenon, and for applied fields of a few thousand oersteds the resonance frequencies lie in the microwave range.

The absorption becomes saturated if the magnitude of the stimulating field is increased and in this situation the populations of the two levels concerned become equal. Bloembergen's brilliant proposal was to take a system comprising three unequally spaced energy levels and to create a non equilibrium population by saturating the transition between the outermost levels, thus setting up the conditions in which a net *emission* of



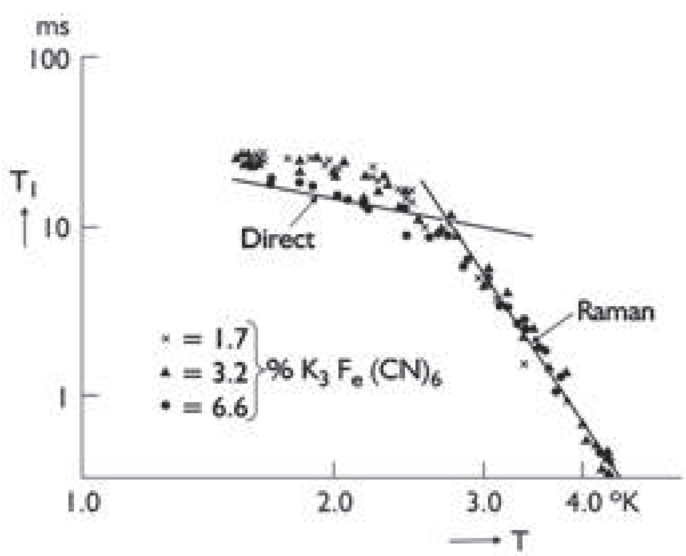

*Three level system showing population inversion*

radiation at the frequency corresponding to the separation of the two upper (or lower) levels can be observed. The concept is illustrated on the left. It is evident that if the population differences between the levels are to be at all significant the system must be maintained at a very low temperature (liquid helium temperatures ie < 4.2K). This is also necessary to reduce interactions between the spin system and the lattice in order that a non-equilibrium population might be maintained. This scheme provides a means of amplifying the microwave signal at the lower of the two frequencies applied to the crystal. What made the idea attractive from a practical point of view was that it offered the possibility of a microwave amplifier having a noise performance vastly superior to that of any other known device thus opening up new realms of system sensitivity. The main reason for this is that no randomly moving charged particles are involved in the amplification mechanism the only intrinsic sources of noise being spontaneous transitions at the signal frequency and losses in the input system.

This was the Solid State Maser (**M**icrowave **A**mplification by the **S**timulated **E**mission of **R**adiation) and early in 1957 Kurt Hoselitz, Alan Ahern and I agreed that it would form part of our programme. There was no requirement for painstaking presentations to any internal authorising body, there wasn't one, although Kurt must have put Peter Trier in the picture, and the Dutchmen didn't become involved until we were well down the track. We just got on with it and there was a lot to get on with. To be more specific, we had to get to grips with the arcane realms of electron spin resonance, of spin lattice interactions, with the choice of materials in which the desired maser action was likely to occur to an optimum degree and with the microwave structures in which to exploit it. Apart from the latter area, where my microwave tube experience was helpful, it was all rather new to us. To be brief we eventually focussed on two materials in which $Cr^{3+}$ was the active ion; these were potassium cobalticyanide plus chromium, and ruby which is aluminium oxide with a dash of chromium (0.05%) – sadly prosaic! There was a certain amount of basic materials work and amongst this were David Paxman's measurements of spin-lattice relaxation times ($T_1$) in maser materials. David, a Cambridge graduate who had spent some time in the Royal Air

Force, joined the section in October 1958 and embarked on these difficult experiments. The measurements which he made on the $Fe^{3+}$ ion in $K_3Co(CN)_6$, a close relative of the chromium doped material, were particularly successful and provided the first unambiguous experimental confirmation of JH Van Vleck's theoretical predictions, made in 1940, of the temperature dependence of these relaxation times. David's work was recognised in glowing terms by Van Vleck himself, a world figure in twentieth century physics, in his keynote address at the International Conference on Quantum Electronics in Berkeley in 1961 – most valuable publicity for the Laboratory.

To achieve a reasonable gain from a solid state maser it was necessary to concentrate the signal frequency fields by use either of a cavity resonant at the signal frequency or a structure able to propagate a slow wave at the signal frequency. The cavity maser is easier but always regenerative and offers very limited bandwidth whereas the travelling wave device, although much more difficult to design and make, is not regenerative and can have a reasonable bandwidth. We made both types of device, cavity masers at S-band, initially using $Cr^{3+}$ in $K_3Co(CN)_6$ and later synthetic ruby which was much easier to deal with and readily available in large perfect single crystals, and travelling wave masers at S-band and at 4170MHz which used ruby. When Mr. Otten, then President of the Philips Concern, and Professor Casimir visited us on 22nd April 1959 we demonstrated a cavity maser to them, Hendrik Casimir, who always understood things perfectly, was delighted with it. Maybe it helped with the Philips funding. However there was almost 100% Government support for the work with five DCVD Research Projects (RP8-14, 15, 17, 24 and 30) and two VX




*Mr. David Paxman*

*$T_1$ Results*

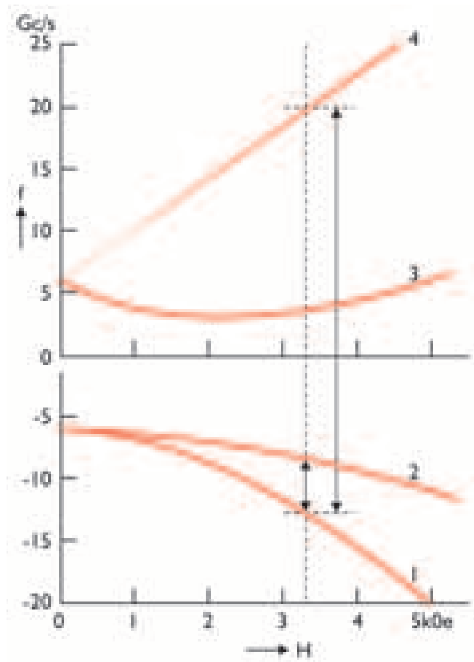
developments VX8525, an X-band cavity device operating at 77K, and the unforgettable VX 8531 a 4170MHz travelling wave maser for satellite communication experiments♣. In January 1961 we demonstrated an S-band cavity maser using a superconducting magnet at the Physical Society Exhibition in London. This was a nice experiment, the input to the maser being switched between matched loads at 77K and 290K using a low loss circulator (from Systems Division) and the outputs displayed and compared. The ratio of the outputs was between 2.5 and 3 clearly showing the maser's exceptional noise performance; the superconducting magnet (c 2,500 oe) wasn't bad either – altogether this demonstration was something of a *tour de force*.

In August of that same year we were approached by the GPO who needed a travelling wave maser operating at 4170MHz as the first stage amplifier in the satellite communication receiver system which they were building on Goonhilly Down in Cornwall as part of the proposed Telstar experiment. The maser was necessary because the signal from the satellite was expected to be no more than $10^{-12}$W – $10^{-13}$W. This was a tall order; it was a new frequency range for us and they wanted at least 20db gain, 25MHz bandwidth and less than 15K noise temperature from a device using a permanent magnet and operating unattended for 8 hours on the back of a large steerable dish aerial. As if that wasn't trouble enough the time scale was a bit tight – they needed the device by April of the following year, oh and by the way, they needed two! Peter Trier was keen to take this on recognising that here was a unique opportunity for the Lab to play a crucial part in an epoch making event in the development of telecommunications. Although the possibility of failure was very real we thought that there was at least an even chance of success so we took up the challenge. The project was funded by DCVD and given the number VX 8531 – never to be forgotten. Dr. Hugh Daglish of the GPO was the Design Authority.

Virtually the whole section was involved in the project in some way, everything else was set aside. Alan Ahern and AJ Tyrell of Mullard Ltd. designed the permanent magnet (in Ticonal G), Peter Bunn and Don Stevenson of the Engineering Division looked after the cryogenic and mechanical aspects, David Paxman and John Orton* addressed the maser material questions and I was responsible for the design of the propagating structure with its heavy dielectric loading. The resources of the Engineering Division were more or less at our disposal and we were well served indeed, in particular by Maurice Kite and Bob Neville but there were many others. When there was something to measure a party from the Radar Section of Systems Division joined us; these included Fred Smith, John Cook, John Day

♣ *In obtaining Government contracts the help of Roy Parry, Mullard Government Liaison Officer, was crucial. Roy, who had joined the Company from Marconi in the late 50s was a tremendous extrovert, quite indomitable and would never take no for an answer! He did wonders for the Mullard infrared activity in Southampton and was deservedly awarded an OBE in consequence.*

and Denis Fletcher, and, again, there were others at various stages. The whole project was my responsibility with Fred Smith in charge of the on-site installation work.

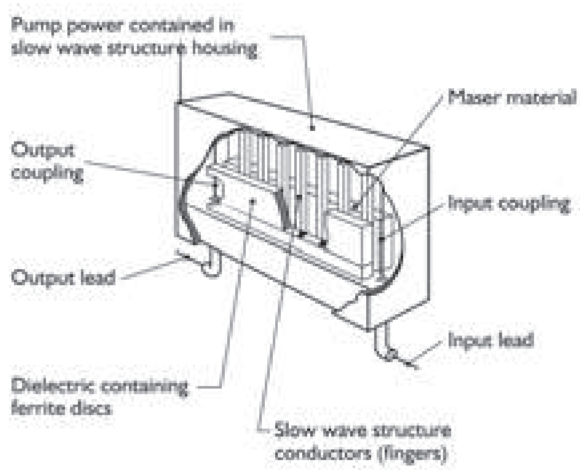



*Ground state splitting of $Cr^{3+}$ in $Al_2O_3$ - Ruby*

Previous experience of these devices suggested that it would be best if the external magnetic field were directed at right angles to the c-axis of the ruby and along the direction of extension of the conductors forming the slow wave structure. The ground state splitting as a function of the magnetic field is shown on the right, and the slow wave structure, the heart of the device, in the figures below and overleaf

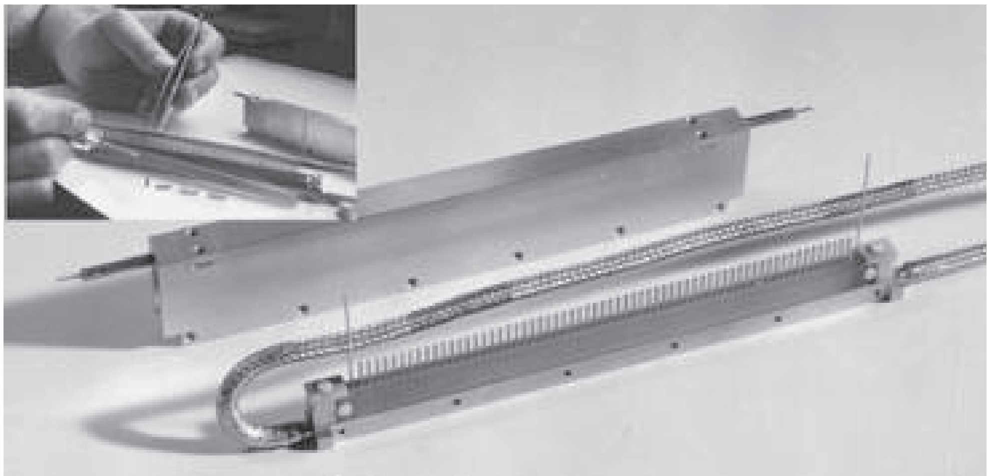
The ferrite discs (actually yttrium iron garnet) shown in the figure below, provided reverse isolation and were cut from a single crystal grown in the Laboratory just down the corridor by John Page. The maser was pumped between levels 1–4 at 30,150 MHz using EMI Klystrons VX 5028 and the signal transition was between levels 1-2 at 4170 MHz. It all worked pretty well first time (it just *had* to) in the laboratory electromagnet with glass dewar vessels. Happily it also worked well with the Hofman metal Dewars, which arrived from the USA in March 1962, and Alan Ahern's superb permanent magnets (also right first time). I do remember though coming in early one morning to find the night shift (yes, we worked shifts towards the end), who had been making the first measurements on the complete device with the Hofman dewar and the permanent magnet, very downcast, looking at a measured noise temperature of 50K. Happily they had made an error in calculating their results and the corrected result was 10K, well within spec.

This stage was reached in April 1962 and in May and June the first device was transported to Goonhilly and installed on the dish aerial by Fred Smith, Ted Hentley, John Cook and Maurice Kite together with the GPO staff. This was a very demanding exercise in a difficult and exposed



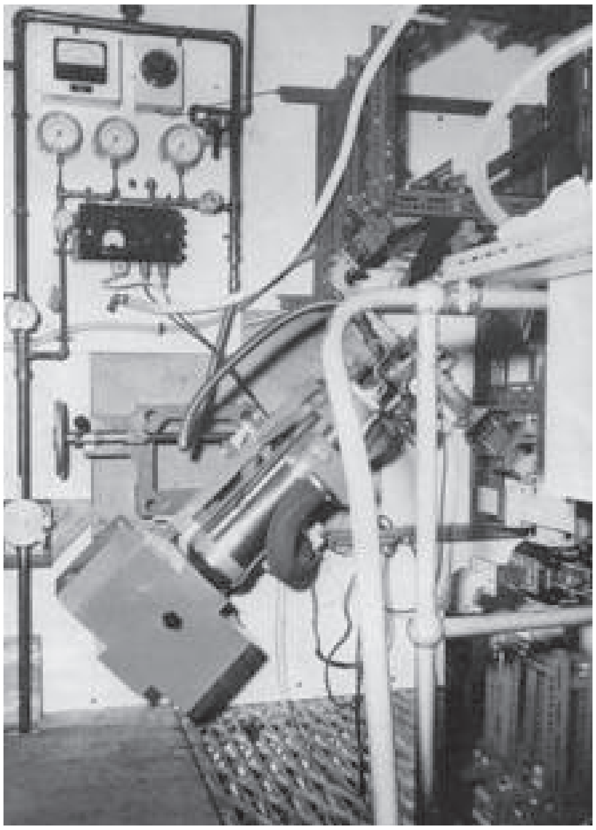

*Slow wave structure section*

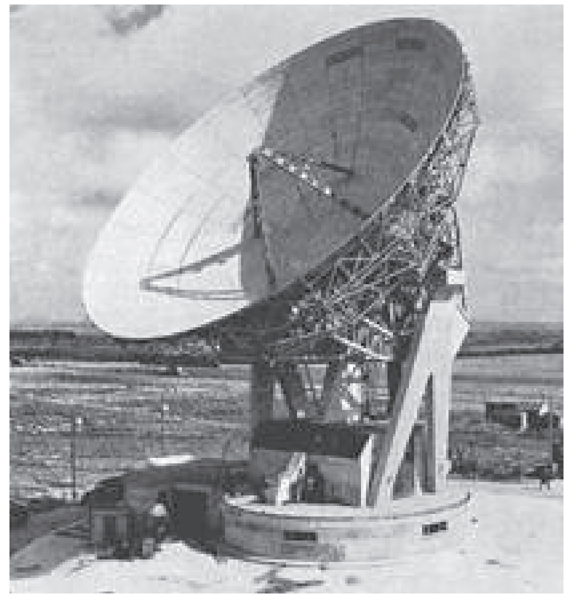
* *John Orton had joined us in September 1960. He had done a DPhil in Oxford on spin resonance and was a recognised authority on the subject. He was a great strength to us, a splendid colleague and a fine cricketer.*



*Slow wave structure*

*Ted Hentley and Fred Smith (right) with the packaged device*





*Dish aerial at Goonhilly and the Maser in its operating position*

environment and it was remarkably well done.

The maser was formally accepted by the GPO on 29th June 1962 and in the small hours of July 11th 1962 duly played its part in the first transatlantic television transmissions via the Telstar satellite. Things were all very marginal on that occasion as a polarisation filter had been wrongly connected in the feed to the maser from the aerial with the result that the signal was greatly reduced. This rather crass error (nothing to do with us) was discovered and corrected during the following day and that night the celebrated live transmissions took place with several Mullard people appearing.

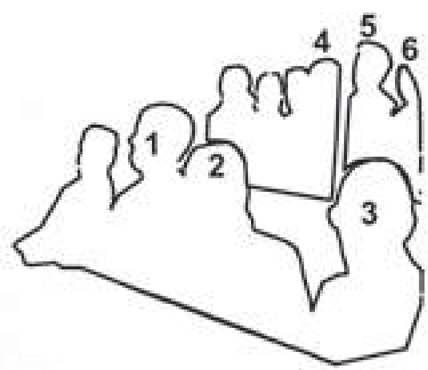
The Laboratory had worked very hard on this one and our efforts were very generously acknowledged by Harold Stanesby in a letter to Peter Trier of 13th July. This was a very big project and it was indeed carried out in an amazingly short time. Further recognition of our efforts was the award of an MBE to me, the Project Leader, in 1965 – I was 36 at the time and this was the first such award made to a member of the Laboratory. It was quite an occasion and Peter Trier gave a celebratory party in the Laboratory. on the evening of New Year's day 1965 (not a public holiday in those days).

Work on masers went on; the Hofman Dewars of the Goonhilly devices were replaced by bigger and much better vessels, designed by Don Stevenson and Norman Wright and built in the MRL workshop, which gave a huge increase in operating time. We also replaced the permanent magnets with superconducting magnets; later maser devices, including a beautiful matched pair of S-band TWMs for Radio Astronomy, were made in the Systems Division. Nothing though ever had quite the same excitement as the first Telstar experiments.

THE TIMES SATURDAY JULY 21 1962

*This advertisement will appear tomorrow in leading newspapers in the United States.*

**It was only eight minutes long…It had no stars, no music, no script…It went on the air at 3:22 am British Summer Time…It was one of the most important television broadcasts ever presented…And, it was carried "live" in the United States, exclusively over the CBS Television Network…**


On Wednesday night, July 11, the first "live" transatlantic broadcast in television history was relayed from the United Kingdom to the United States via the newly launched Telstar satellite.

The CBS Television Network—the only network to carry the event when it occurred—brought the broadcast to 6,000,000 American homes. Presented as a special report by CBS News, the broadcast originated in the control room of the British General

1. R.White (GPO)
2. Neil Booth (GPO)
3. FJD Taylor (GPO)
4. John Day (MRL)
5. John Cook (MRL)
6. Fred Smith (MRL)

*Live transmission*

DR. WALLING

COPY

G.P.O.

Engineering Department,
Research Station,
Brook Road,
Dollis Hill,
London, N.W.2.

HS/832

13 July, 1962

Dear Trier,

The excellent results recently obtained at our Goonhilly Station on Telstar must have given great satisfaction to you and those members of your staff concerned with developing the Maser amplifier that we used there.

I should be glad if you would express my thanks and appreciation to all concerned for an excellent piece of work carried out in an amazingly short time.

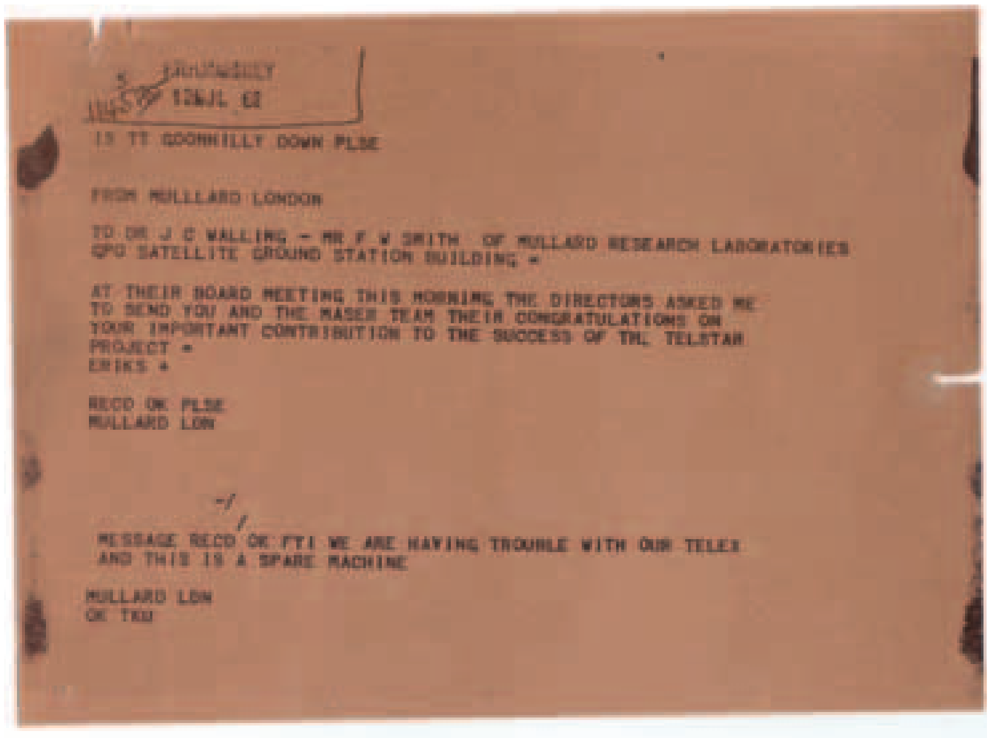
Yours sincerely,

(Sgd.) Harold Stanesby

(H. STANESBY)
Deputy Director of Research.

P. E. Trier, Esq., M.A.,M.I.E.E.,
Mullard Research Laboratories,
REDHILL, Surrey.

*Harold Stanesby's letter of thanks*



12JL 62

IS TT GOONHILLY DOWN PLSE

FROM MULLLARD LONDON

TO DR J C WALLING - MR F W SMITH OF MULLARD RESEARCH LABORATORIES
GPO SATELLITE GROUND STATION BUILDING =

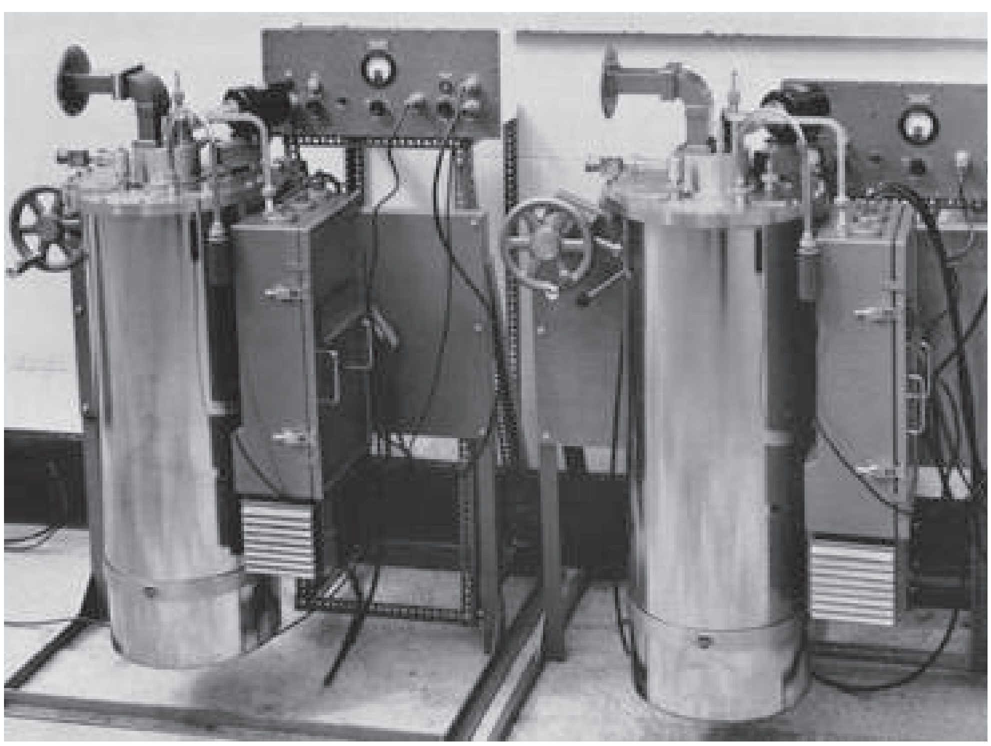
AT THEIR BOARD MEETING THIS MORNING THE DIRECTORS ASKED ME
TO SEND YOU AND THE MASER TEAM THEIR CONGRATULATIONS ON
YOUR IMPORTANT CONTRIBUTION TO THE SUCCESS OF TH, TELSTAR
PROJECT =
ERIKS +

RECD OK PLSE
MULLARD LDN

MESSAGE RECD OK FYI WE ARE HAVING TROUBLE WITH OUR TELEX
AND THIS IS A SPARE MACHINE

MULLARD LDN
OK TKU

*SS Erik's telex to John Walling and Fred Smith*



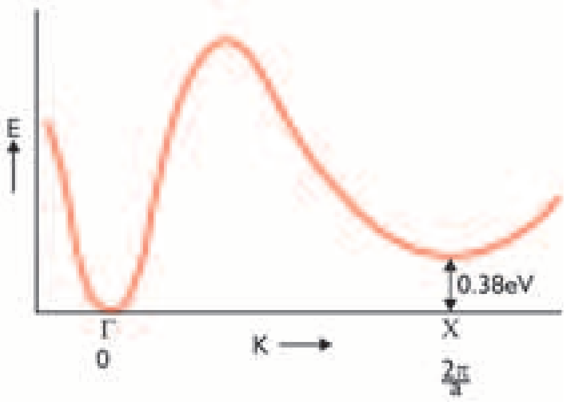
*The S-band Masers for RSRE*

**Semiconductor Physics and the Transferred Electron Effect**

The semiconductor activity in SSP was greatly strengthened in this period. Fenia Berz and Hugh Wright transferred from VPL towards the end of 1956, Brian Ridley, having completed a PhD in Durham, joined in 1956 and Peter Newman in 1955. Peter was a Cambridge graduate who had worked for the Admiralty during the war and prior to coming to MRL had been in the National Coal Board Laboratories; he was related to Sir Keith Joseph (a member of the Thatcher Government) and there was a distinct family resemblance. Semiconductor compounds were his sphere and he was particularly enthused by Gallium Telluride, whether this was triggered by a year in the Nat Lab in 1959/60 is unclear but, for whatever reason, a large project on it was initiated. Carole Fisher, who was to have an important part in many projects over the years, joined us in 1961 and was concerned with preparing the material. Nevertheless the project was not a success and, somewhat to Newman's chagrin, was replaced by work on 3-5 compounds in 1962 or 1963. We thus were late entrants to the 3-5 field and the consequent lack of well controlled good quality gallium arsenide prevented Brian Ridley and his collaborators from demonstrating the transferred electron effect in the material in which its manifestation is most spectacular.

*Dr. Brian Ridley*

Brian Ridley had been looking at the basic theory of semiconductors and together with Tom Watkins recognised in 1960 that a dynamic negative resistance could occur in a multi-valley semiconductor as a consequence of electron transfer between two conduction band minima. The effect can be understood by reference to the sketch of the structure of the Gallium Arsenide conduction band. Electrons in the conduction band are normally confined to the central minimum but, because of the high mobility associated with this part of the band, they can acquire sufficient energy from an applied electric field to transfer to the X-minima. They also need to effect an exchange of momentum with the lattice but this is not a problem. The mobility of electrons in the X-minima is some twenty times less than that of electrons in the central valley so the transfer results in a sharp drop in average drift velocity with a consequent reduction in current through the sample. The possibility of making a negative resistance oscillator was thus apparent. Ridley and Watkins also pointed



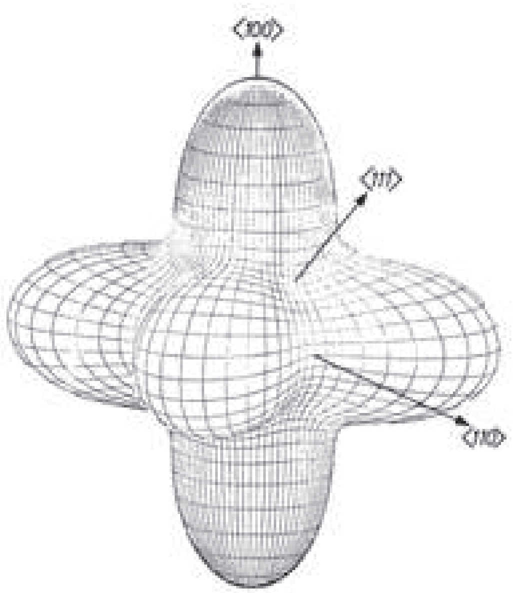

*GaAs conduction band*

out that the effect might be observed in strained Germanium although in that case it would most probably be less dramatic than in GaAs. Their work on this completely novel effect, the Transferred Electron effect which became known as the Ridley–Watkins effect, was published in 1961.

Similar work, in which the 3-5 compounds were examined more extensively, was published in 1962 by Cyril Hilsum (then at SERL Baldock – a Government Laboratory) and it was later realised that the microwave oscillations observed by JB Gunn of IBM in bulk GaAs were due to the Ridley-Watkins effect. Tragically, as a result of a virus picked up on a visit to the USA, Tom Watkins died before the importance of his work was recognised. Brian Ridley left the Laboratory in 1964 to become one of the founder members of the Department of Physics in the then new University of Essex. He was elected to Fellowship of the Royal Society in 1994 and is now Professor Emeritus in Essex. His was a comparatively short period in the Laboratory but he made a great impact as a scientist, a wit and a splendid colleague.

**Ferrites and Garnets.**

The remaining major area of work in the SSP Division was that of the magnetics section whose principal concern was with the properties of single crystal ferrites and ferrimagnetic garnets. Systematic measurements of magnetisation, magneto crystalline anisotropy and magnetic resonance were made on a range of single crystals, grown with meticulous care by John Page.



*Anisotropy energy surfaces for Samarium Iron Garnet*

This work was of outstanding quality and received world wide recognition reflecting very positively both on the Laboratory and on those involved, Fred Harrison, Ron Pearson, Ken Tweedale, John Knowles, Dick Teale, Barry Clarke and John Page being the principal participants. A particularly beautiful example of the results of this work is that of the anisotropy measurements made by Ron Pearson and his collaborators on samarium iron garnet.

This basic work shed light on the processes contributing to microwave losses and

disaccommodation effects (slow changes in permeability with time) in these materials and was thus of real relevance and practical importance to a major area of the Company's business.

## THE SYSTEMS DIVISION

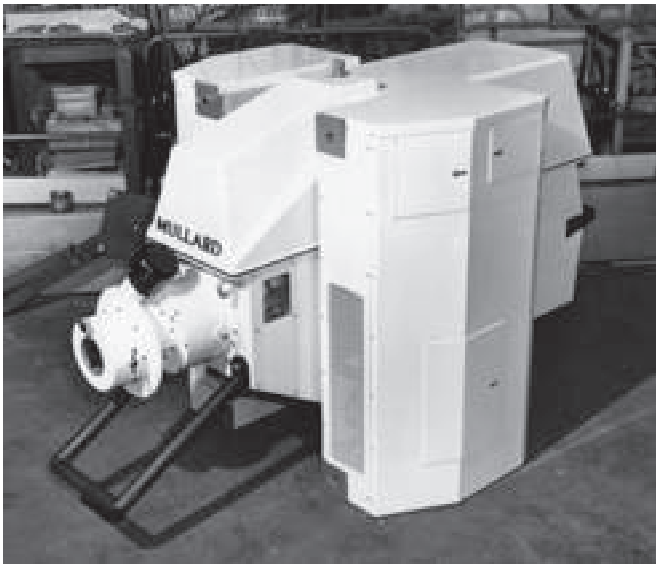
### Linear Accelerators.

In 1961 the production of linear accelerators was transferred from the Laboratory to MEL. Several members of staff moved to MEL and formed the nucleus of a new production activity, these included Tom Chippendale, Alistair Campbell and others. Prior to the transfer however no less than nine machines had been built and tested in the Laboratory and successfully installed at the customers' sites. This was a massive undertaking calling for tremendous support from the designers, drawing office, workshops and all the services in its successful achievement.

Although the later machines were mostly for medical purposes (photo below) one was an industrial radiographic machine. This was an entirely self contained 6Mev accelerator which enabled *in situ* examination of large and difficult welds such as those in nuclear power station pressure vessels. It is illustrated overleaf.

A rather different exercise was that conducted in collaboration with MEL and the

*Liverpool Linac*



*6Mev accelerator*

NIRNS Daresbury Laboratory to make a 40MeV injector for the 4GeV Electron Synchrotron then under construction.

Research work in support of the MEL commercial activity continued in the Laboratory but on a relatively small scale. The MEL business in Linacs developed very successfully, it concentrated on medical applications and was transferred to Philips Medical Systems. It was sold at the end of the 90s with a production and sales rate of about 120 machines per year at about £0.5M each.

**Instrumentation.**

An interesting activity in the Instrumentation section in this period was that concerned with Nuclear Magnetic Resonance Spectrometry under the aegis of Brian Evans. It had started in 1954 as a support programme on permanent magnets for AJ Tyrell, of Mullard Ltd.

*Mr. Brian Evans*

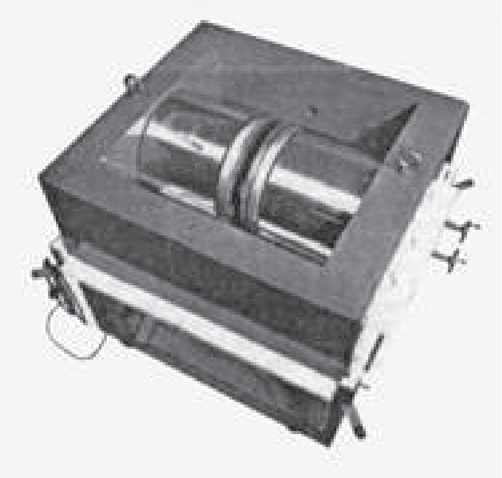
One of Tyrell's customers required a large permanent magnet providing a field of about 7,000 oersted of very high uniformity over a volume of several millilitres for nuclear magnetic resonance experiments. This was Professor Sir Rex Richards of the University of Oxford and he wanted a permanent magnet because it offered a greater stability of field with respect to time and ambient temperature variations than did an electromagnet. A suitable magnet, illustrated opposite, was designed and made, the poles comprising four slabs of Ticonal G each 13" in diameter and 3" thick with soft iron pole pieces having optically flat faces, and its performance measured using a "Pound" NMR spectrometer, which incorporated one of the precision variable capacitors constructed for the earlier receiver programme. The magnet was delivered to Prof Richards early in 1957 and was remarkably successful enabling the observation of NMR spectra with a resolution of better than 1 part in $10^8$.

The success of the Oxford NMR magnet led to a programme directed at the design and construction of a commercial high resolution nuclear magnetic resonance spectrometer. This drew on the expertise of Ken Ainslie in receiver design and the design

skills of the Engineering Division and had rather a superior performance offering a resolution of 1 part in $10^8$. The machine is shown in use below.

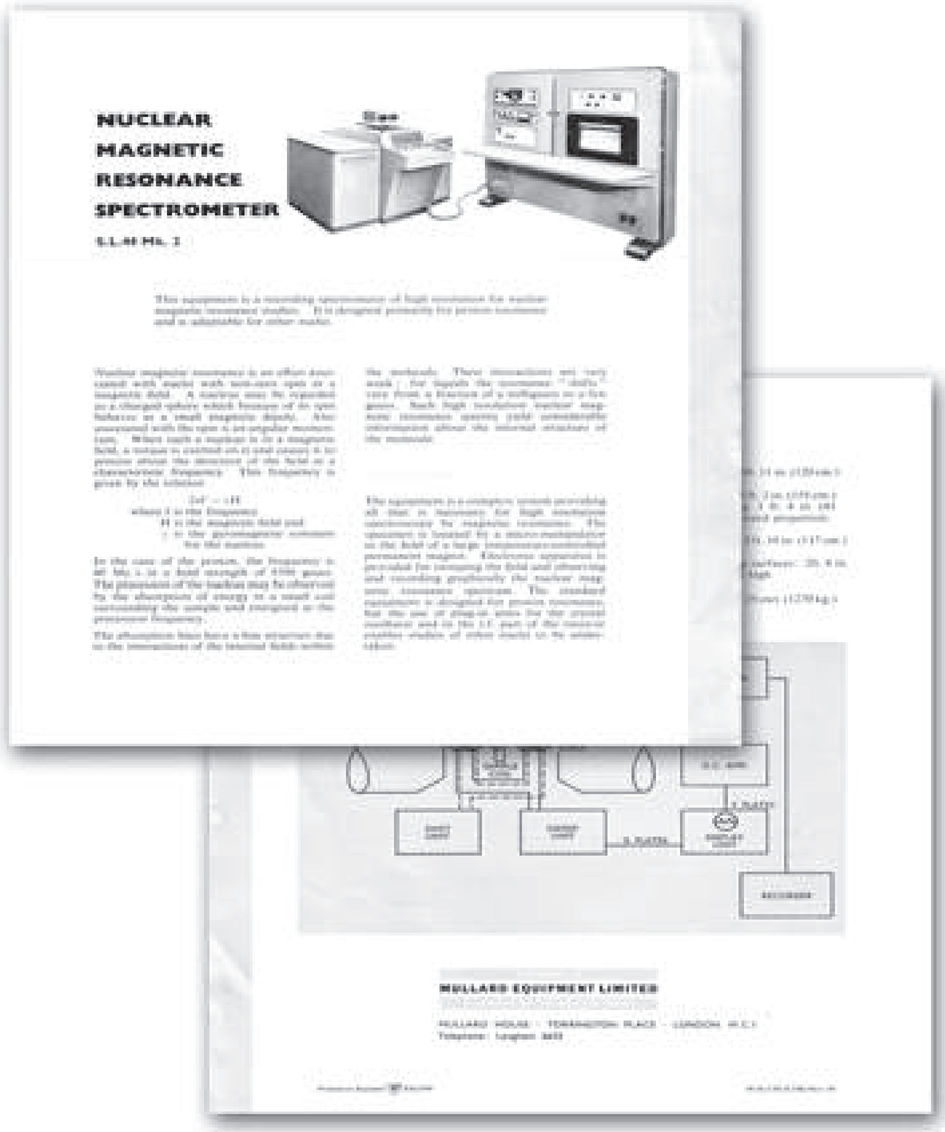
A small commercial activity in complete nuclear magnetic resonance systems using permanent magnets then developed, together with MEL,

This was the world's first commercial high resolution permanent magnet NMR system and formed the prototype for a batch of four 40 MHz machines constructed jointly with MEL and a further machine operating at 32 MHz was made for Birmingham University. In 1962, however, following a detailed commercial study of the world market, MEL decided not to pursue the activity.



*NMR magnet*

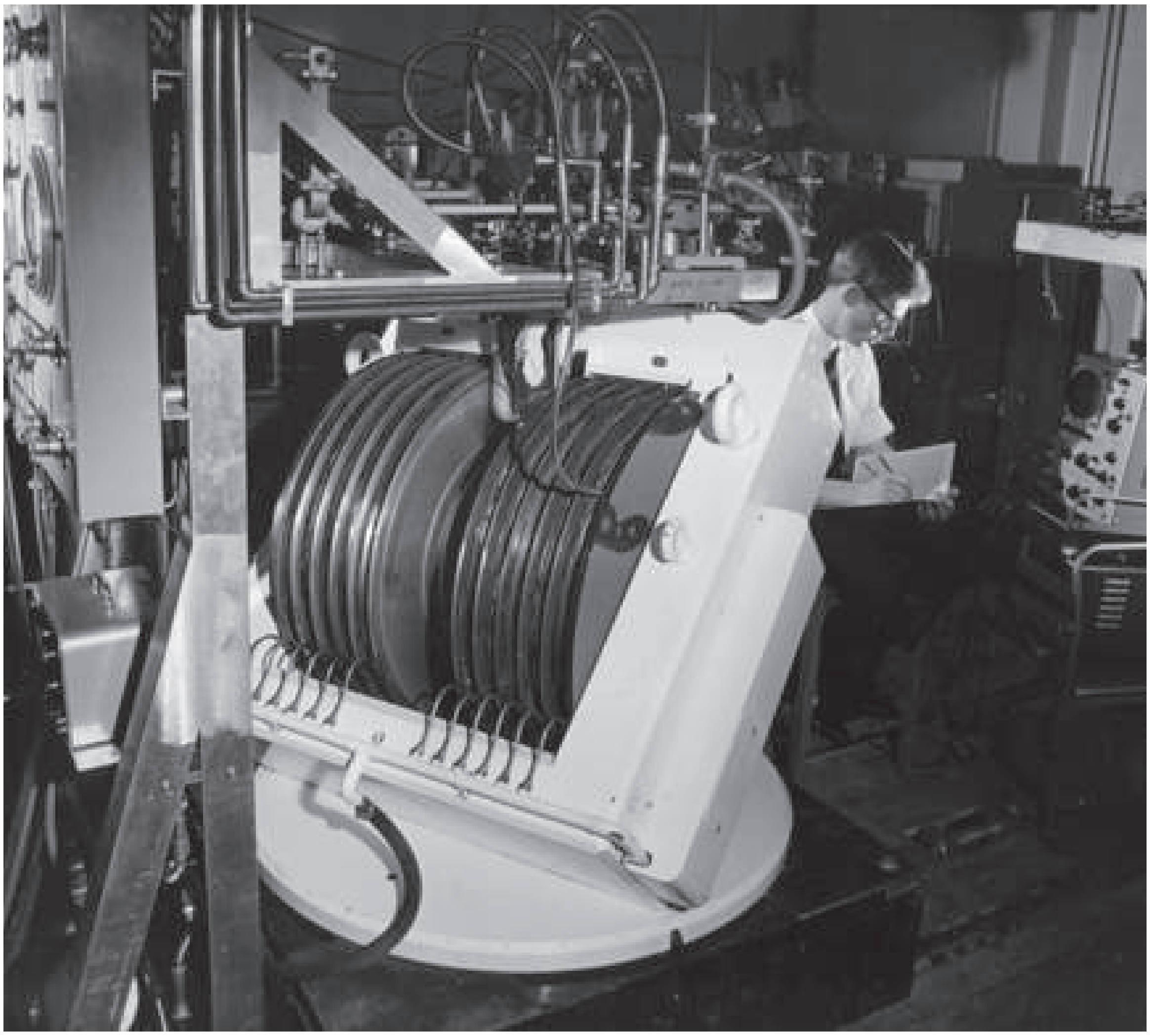
*NMR spectometer system*




*NMR spectrometer brochure*

A programme on Special Magnets developed in parallel with the NMR spectrometer work exploiting the expertise in design and precise measurement of performance. These were electromagnets, driven by high current, highly stabilised motor generators, the control circuits for which were designed by Harry Knowles and built in the Laboratory. Several such magnet systems were built and supplied to outside customers including two 12" magnets, one 16kW and the other 20kW, to the Clarendon Laboratory in Oxford, and several more to other UK Universities and industrial users. Although this was a very

competitive system, superior in many ways to others in the field, an attempt to transfer the activity to Mullard Mitcham and to put it on a proper commercial footing did not succeed. However the availability of an internal laboratory capability in the design, construction and control of large electromagnets (up to 12" pole piece diameter) was extremely useful, indeed crucial, to work in other areas of the Laboratory, notably that on magnetics, ferromagnetic resonance, spin resonance and masers in SSP. At one time in the maser work we had three such magnets, all with their motor generators (tucked away in the service ducts) and controllers (Knowles boxes). Although perhaps we rather took them for granted these were outstandingly versatile and reliable systems affording exceptional performance.

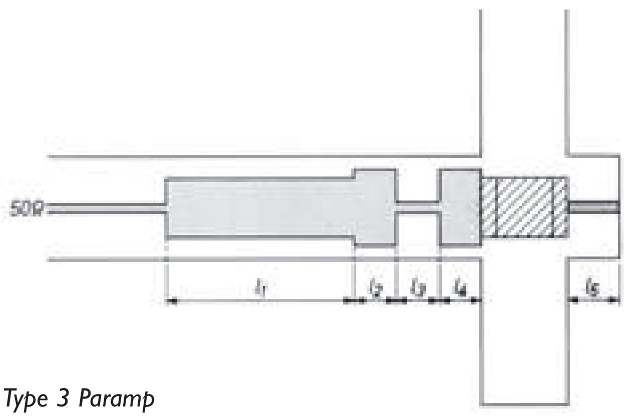


*Electromagnet with Barry Clarke*

**Parametric Amplifiers.**

Whilst solid state masers, such as those built in MRL for the Goonhilly Earth Station (as it became known) provided the lowest noise temperatures attainable in a microwave amplifier it is undeniable that they were complicated, expensive and difficult to use in the field. The fact that the maser demanded liquid helium for its operation was probably its biggest practical drawback. In this situation it was entirely natural that alternative low noise devices should be actively pursued in the Laboratory and diode parametric amplifiers operating at microwave frequencies were the subject of a major programme in this period.

In essence, in such a device it is arranged that a variable capacitor forms part of a circuit resonant at the signal frequency. Then, if the magnitude of the capacitance can be varied at a rate higher than the signal frequency, energy can be transferred to the signal, which is thus amplified. The variable reactance diode (varactor), in which the effective diode capacity is dependent on the voltage across it, provides an ideal means of realising such a configuration and a team led by Phil Allin and Colin Aitchison used Mullard varactor diodes CAY10 to realise devices having a microwave performance summarised in the table. The devices themselves are configured as shown.



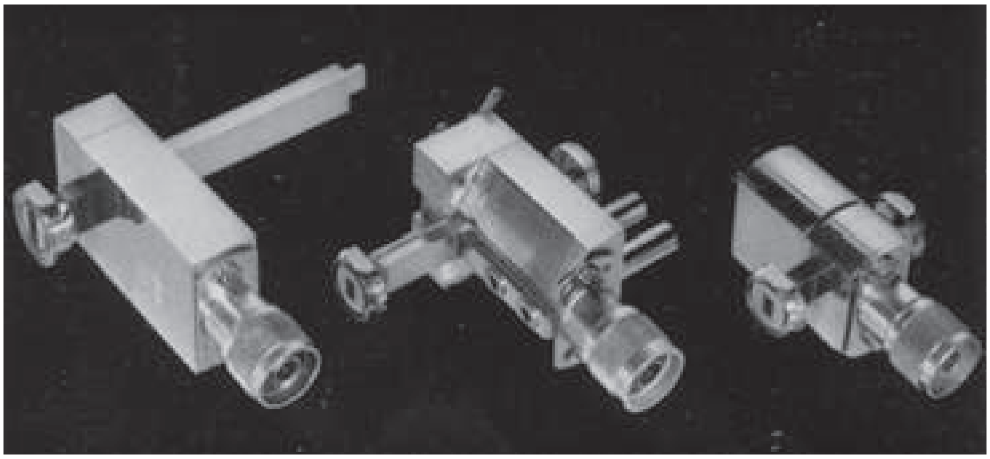

*Type 3 Paramp*

| Signal Frequency GHz | Pump Frequency GHz | Noise Temperature °K | 3dB band width at 20dB gain MHz | Pump Power mW | Tuning Range MHz | Varactor Type |
|---|---|---|---|---|---|---|
| 3.0 | 33 | 95 | 25 | 20 | 150 | CAY 10 |
| 5.6 | 39 | 140 | 50 | 50 | 250 | CAY 10 selected |
| 9.0 | 33 | 190 | 50 | 20 | 500 | CXY 10 |

*Parametric amplifier performance*

The devices have a good noise performance, which, although it would not have been sufficient for the Telstar experiments in satellite communications, proved entirely adequate for subsequent systems employing more powerful satellites. Amplifiers of this type eventually displaced the masers at Goonhilly.

Of those principally concerned with the paramp work, Phil Allin joined the Cambridge University Press in a senior role, whilst Colin Aitchison entered the academic world, eventually becoming a Professor in Brunel University and subsequently Surrey. Several years

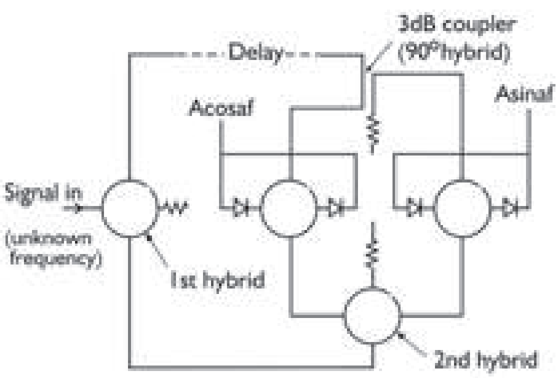


*Three type 3 Paramps*

later John Williams joined GEC, where he eventually became Managing Director of GEC Research Ltd. and was thereafter appointed Chief Executive of the IEE. A distinguished body of men indeed.

**Microwave Systems - Radar.**

The highly classified programmes on Radar systems continued apace and with huge success during this period, Steve Robinson's earlier invention of the phase reversal wide band hybrid providing the key to a range of new inventions and systems. Possibly the most important of these was Steve's invention of a system for Instantaneous Frequency Measurement. The principle can be understood if one notes that the phase change occurring along a length of a transmission line is linearly dependent on frequency, thus a measurement of the phase change in a known length of line determines the frequency. To effect this Steve devised the scheme illustrated. The incoming signal of unknown frequency is split into two equal amplitude components by the first hybrid, one component is delayed, using a known length of line, with respect to the other and then further split in a 90$^{o}$ strip line coupler whilst the undelayed component is split by a second hybrid. These signals form the input to a pair of wide band balanced mixers the output of one mixer being of the form Asin(af) and that of the other, because of the 90$^{o}$ shift, Acos(af), af being the phase




*Sketch of IFM circuit*

difference introduced by the delay. This system has great advantages, the two signals can be combined to produce an elegant "clock" display the angle being determined by the phase difference and hence the unknown frequency; further, phase ambiguity resolution is easy and digitisation is not difficult (according to Steve). This IFM system was probably the single most important invention made in the Laboratory during the whole of its existence to date.

The system was immediately adopted by GCHQ and various equipments using it were manufactured by MEL for a number of octave bands in the microwave spectrum. A most important system was "Porker" which employed IFM and was designed jointly with MEL. The IFM was used to tune four conventional superheterodyne receivers (employing valves!) for bearing measurements.

Following "Porker", a great deal of work was carried out, notably by Robert Alcock and Peter East, on digitisation of the systems. The main outcome of this was the development of the extremely successful "Abbeyhill" system in the late sixties which remains in service, with evolutionary changes, to this day.

## REFLECTIONS ON AN ERA

This was undoubtedly one of the most successful and exciting periods in the history of the Mullard Laboratory, the following events and achievements being particularly noteworthy:-

a) A major interdivisional project was successfully mounted to realise and demonstrate a wholly novel colour television display system, the Banana Tube system. This although it did not result in a new product for the Company it showed very convincingly that the Laboratory was able to take a complex project through from a basic idea to the realisation of a complete system.

b) The programme on night vision devices and systems was started. This was to be a salient feature of the Laboratory's work for many years and a major product activity for the Mullard Company.

c) The design, construction, testing and installation of the Goonhilly masers in little over six months provided a further clear demonstration of the all-round capability and commitment of the Laboratory, this time in a project of the highest technical sophistication and unparalleled urgency. One has to wonder, however, why it was that we were given so little time in which to do the job when other crucial parts of the GPO Earth Station's equipment such as the dish aerial and its control system and the high power transmitter

with its 6.39GHz 5kW travelling wave tube (made at SERL by a team led by Mike Bryant) had much longer. An internal GPO memorandum in my possession (set aside and overlooked at the time and forgotten until now) however makes it perfectly clear that as late as the summer of 1961 they had planned to make the maser in their Dollis Hill Laboratory. It also makes it perfectly clear that, at that time, they had neither the resources in place, nor the necessary detailed know-how, to do so. Thus they realised, rather late in the day, that it was beyond them and therefore, swallowing their pride*, they came to us to get them off the hook. Indeed there was nowhere else in the UK, with anything like our capability in the area at that time, where they could have gone. However, they were not unreasonable people to work with and the whole project was a wonderful and most memorable experience which we felt very privileged to have shared. Although the maser work did not lead to a commercial activity, it certainly helped to put the Laboratory on the map.

d) A completely new effect in semiconductor device physics, the Ridley – Watkins effect, was discovered and demonstrated in the Laboratory and shown to be the origin of the "Gunn" oscillations observed in 3-5 compounds.

e) The successful development in VPD of the communications travelling wave tube, the LB6-20 resulted in a £1M order for Mullard, effectively launching the business of the Microwave Division.

f) It was the Radar systems work though which had probably the greatest impact and long term importance; it put MEL in a uniquely advantageous position to exploit the huge and lucrative military market so important to their business. In the Annual Report for 1965/66 Peter Trier comments that a large scale military project (Porker) originated by the Microwave Systems Group (radar) had resulted in orders worth £3M. Also the transfer of the Linear Accelerator work to MEL similarly established a new and valuable product activity for the Company, which proved to be a mainstay of its future business with an eventual turnover in excess of £10M pa.

Any lingering doubts about the value of the Laboratory to the Mullard Company and to the Philips Concern must surely have been wholly dispelled by its outstanding success in this period. MRL could not rest on its laurels though, but could certainly address the challenges lying ahead with the confidence born of success.

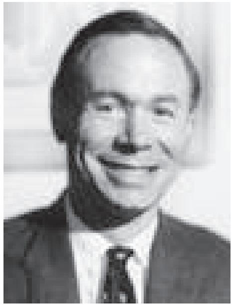
* *This would have been very difficult for them since, as an organisation, they had the most amazing corporate ego. In that connection, Peter Trier recalled an occasion in the mid seventies when an ERC meeting, chaired by Prof RV Jones, considered a report, presented by Kurt Hoselitz, of a working party on Ultra Pure Silicon, which he, Kurt, had chaired. John Bray, then Director of Research in the GPO, when asked to comment, said "Well, yes, it's quite a nice report but I think that we know all that we need to know about ultra-pure silicon in the Post Office". KH, outraged, rose to his feet and said "Mr. Chairman! - The remarks we have just heard from Mr. Bray are a typical sample of that mixture of ignorance and prejudice to which we have all become so amply accustomed from the Post Office" (I couldn't possibly comment!).*

## CHAPTER FOUR

# A TIME OF CHANGE AND THE END OF AN ERA 1965 - 1969

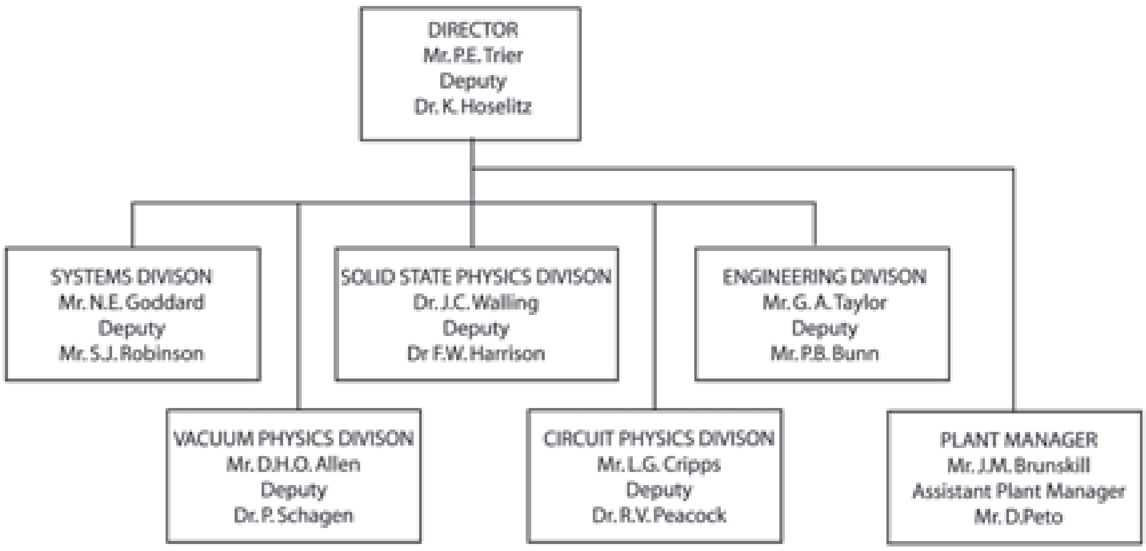
### LABORATORY ORGANISATION

During this period several changes in the Laboratory management took place. Shortly before its start Bryan Overton had been appointed Plant Manager of the Mullard complex in Mitcham and was succeeded as Head of the Circuit Physics division by Graham Cripps. Kurt Hoselitz, who had been appointed Deputy Director of the Laboratory in 1964, decided early in 1965 that it was not practicable to try to combine this role with that of Divisional Head of SSP. This was a decision made jointly with Peter Trier and was, to some extent, a consequence of the latter's increasing external commitments. Somewhat to my surprise I was selected as successor to Hoselitz and assumed the role in May 1965. Also in mid 1965 Ron Godfrey, who had headed the Systems Division since its formation, took up another senior appointment as Technical Manager of the Telecommunications and Defence Systems group at the MEL Equipment Company and was succeeded as Systems Divisional Head by Norman Goddard. This was most certainly not a surprise as Norman had been Ron Godfrey's de facto deputy for many years, was a founder member of the Laboratory and an acknowledged authority on radar systems. Peter Bunn, who had been a key member of the Low Temperature section of SSP since he joined the Laboratory in 1957, was appointed to be Deputy to George Taylor as Head of the Engineering Division at the end of 1965. The post of Deputy Divisional Head was formalised at about the same time. We thus ended 1965 with the following organisational structure overleaf: -



*Mr. Graham Cripps*

*Mr. Ron Godfrey*




The other support functions continued essentially unchanged as follows:-

| | |
|---|---|
| Administration | Mr. FO Munns |
| Purchasing | Mr. PI Pleasance |
| Personnel | Dr. SA Ahern |
| Plant Maintenance | Mr. TF O'Donoghue |

Ken Caple, who was the previous Plant Manager, had moved to Century House in the early sixties and had been succeeded by John Brunskill. At about the same time Pat Pleasance succeeded Jack Theobald in Purchasing.

Pieter Schagen had been appointed Scientific Adviser to the Laboratory, as such he enjoyed the same status as the Divisional Heads but did not have the same administrative responsibilities. This paralleled similar appointments in Philips Research, particularly in the Nat Lab, made in recognition of outstanding scientific and technical achievement. An earlier, transient, Scientific Adviser had been Dr. FA (Eddie) Kroger who was seconded to SSP from the Nat Lab in 1961 or 62 but, after a short stay in MRL, accepted a Professorship in the University of Southern California, La Jolla and left us. He was a very able and eminent solid state physicist but he did not stay long enough in MRL to make a real impact.

**Solid State Physics** (122 staff)

At the end of April 1965 the Solid State Physics Division numbered 122 staff, almost twice the size of each of the other scientific Divisions, and there were nine or ten sections. To make the task of managing this large party more accessible when it became my

responsibility I, with the agreement of Trier and Hoselitz, divided it into three Sub-Divisions each with a Sub-Divisional Head reporting to me. The Sub-Divisions were:-

**Magnetics:** Fred Harrison: comprising Quantum Electronics (John Orton), Thin Films (Charles Fuller) and Magnetics (Ron Pearson).

**Semiconductors:** Julian Beale: comprising Semiconductor Physics (Peter Newman), Semiconductor Devices (Peter Daniel) and Surfaces (Fenia Berz).

**Chemistry:** Eric Millett: comprising Analysis (John Roberts), Crystal Growth (John Brice) and Chemical Technology (Ron Gill)

In addition the Laboratory computer, the Elliott 503, operated under the aegis of Ken Tweedale in the Magnetics subdivision until transferred to CPA in 1967.

The Sectional structure in the other Divisions in 1965 was as follows:-

**Systems** (77 staff)

Here there were two Sub-Divisions viz:-

**Microwaves:** Steve Robinson: comprising Semiconductor Devices (Colin Aitchison), Masers (Fred Smith), Ferrite Devices (Brian Humphreys), All Metal Devices and Microwave Systems (Steve Robinson).

**Electronics:** Cliff Braybrook: comprising Signal Processing (Peter Joanes), Instrumentation (Brian Evans) and Particle Accelerators (Gordon McGinty)

**Vacuum Physics** (77 staff)

Electron Emission (Ted Windsor), Gas Discharges (George Weston), High Vacuum (Norman Robinson), Image Intensification (Pieter Schagen), Microwave Tubes (Nick King), Electron Optics (Brian Manley), E-Beam Technology (Nick King).

**Circuit Physics** (62 staff)

Display (Richard Jackson, Ken Freeman), RF/IF (Ken Moulding), Computers I (Ted Eilley), Computers II and Device Assessment (Ray Peacock), Automotive (Derek Skoyles), Ferrites (Eric Snelling).

**Engineering Division** (172 staff)

Although primarily concerned with providing specialist services to the scientific divisions the Engineering Division also undertook a significant amount of development work into a range of engineering and process techniques required to support the mainstream research programmes. This work was largely carried out in the areas of Numerically Controlled Machines (David Tremlett), Computer Aided Design (Stan Phillips) and Metal Joining (Don Stevenson).

This listing of the sectional structure of the Divisions as it was then gives an idea both of the size of the Laboratory and of the range of its activities.

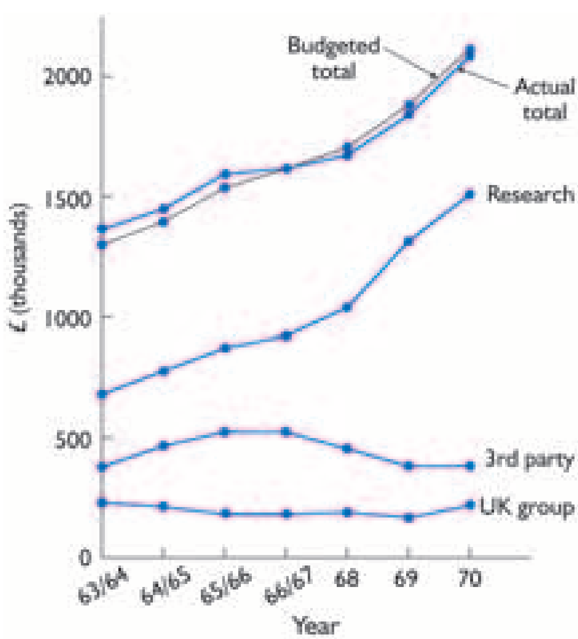
In time we came to realise that the Sub-Divisions were not a good idea as they introduced an extra tier of management and the situation became rather absurd when Deputy Sub Divisional heads were proposed in Systems. The scheme was abandoned in 1969 following the third Eastbourne Conference.

**A NEW BUILDING**

In 1966/67 F Block was constructed on the South Site. This is a three storey block similar in style to the other blocks extending North and South and joining the western end of D Block. Systems Division and the Library moved into F Block making extra space available in the other buildings which, among other things, eventually permitted the Director and Deputy Director together with the Plant Manager and the Personnel Department to move their offices to the South side. The Vacuum Physics Division remained on the North site but the other scientific divisions were wholly on the South site.

**FINANCES**

The annual expenditure of the Laboratory over the period from 1963/64 to 1970 (the reporting year changed from the UK fiscal year to the calendar year in 1968) is plotted in the figure. In the period the total expenditure rose from £1.40M to £2.08M, the whole of the increase being met from the Concern Research funds. The initial rise in third party funding (Government) shown was a consequence of a bizarre episode in 1963 when ASRE, upset by cost over-runs in MEL, withdrew support for the whole ESM programme in MEL and MRL and took their business to Elliott and Ferranti. This move was a failure and, doubtless somewhat abashed, the Establishment returned, a year or so later, to MEL/MRL for their radar systems work taking advantage of the digitisation work which had continued in the Laboratory despite the lack of external support.




*Annual expenditure*

During this period Government support for Industrial Research took a new turn in so far as a greater emphasis on Civil contracts developed with the aim of improving productivity and competitiveness. Generally such contracts were on a shared cost basis raising a whole raft of problems concerning property rights, commercial confidentiality and royalty payments which were exacerbated by the inexperience of some of the government departments concerned. We nevertheless considered it essential to participate in these joint enterprises.

In the period from 1965 to the end of 1969 the total number of staff in the Laboratory fell from 655 to 628 and the cost per person rose from £2,390 to £3,355. Salaries and staff costs contributed slightly more than half of this, which is chastening to reflect on in the light of salary levels in 2004.

**PROGRAMME PLANNING**

Prior to this time the determination of the Laboratory programme was not particularly well controlled although it had moved on from the very early days when the main criterion had been the obtaining of financial support for a project. Nevertheless there wasn't a great deal of interdivisional cohesion and, in many areas, there was a lack of transparency as to the rationale for certain projects. Norman Goddard seems to have felt this particularly in the Systems Division when it became his responsibility but I think that it was probably true to some extent in the other divisions also.

Something had to be done and Kurt Hoselitz as Deputy Director formalised a system of programme planning. This required every proposal for a new project to be supported by a full statement of the rationale for the work, a summary of the prospective benefit for the Company and of Product Group need or interest, the resources required in terms of staff, space, engineering support and equipment, money and time. The source of funding was also identified. This information was summarised on a project proposal form or "top sheet" and considered in detail in the course of a presentation by the proposer(s) to the newly formed Programme Planning Committee. The PPC comprised the Director and Deputy Director, together with the Divisional Heads and their Deputies and occasionally the Plant Manager. The Committee, initially chaired by Hoselitz, had a full time secretary, the Management Services Officer, who was concerned with all aspects of programme planning and evaluation. This was a new post and the first incumbent was Alec Fruin, a Cambridge graduate and a former member of the Solid State Physics and Systems Divisions, who had worked on Maser

devices and materials*. In addition to the PPC itself, the ultimate PRL programming body, several specialist programme panels were appointed some years later. These included the Semiconductor Panel, the Television Panel, the Thin Film Panel and others. These panels, normally chaired by a member of the PPC, would consider initial suggestions for projects in their areas prior to preparation of a full-blooded proposal, review progress of existing projects and in time prepare reviews of their areas for discussion in the PPC. This scheme evolved into a sound practical structure for project initiation, evaluation and review, ensuring, as far as possible that we had a coherent, well considered, Laboratory programme rather than a group of largely unrelated divisional enterprises. The downside of it all, from the Divisional Heads' point of view was that we had to "get inside" proposals coming from other divisions in order to treat them properly adding a new dimension to our already very large responsibilities. I suppose it was good for us.

Consideration of the programmes didn't end there, however, as, because of the increasing Concern support for our work and the establishment of other Philips Laboratories in France, Germany and Belgium, a number of International Research Committees were set up. These were concerned with Semiconductor Devices and Integrated Circuits (SDIC), Semiconductor Microwave Devices, Tubes, Device Circuits and Fundamental Solid State and there may well have been others. They were, in principle, advisory bodies but there was always a touch of the "only a suggestion - but remember who made it" syndrome about them.

There was also the matter of interaction with the Product Groups both nationally and internationally. In the Semiconductor area in the UK this question had been enormously complicated by the establishment, in the early 60s, of a joint GEC/Mullard Company for the manufacture of semiconductor devices. This was Associated Semiconductor Manufacturers, ASM Ltd, to which Mullard brought the Southampton factory and access to MRL (in part) and to which GEC brought a factory in Stockport and access to part of the justifiably famous Wembley Laboratory. The idea for ASM apparently originated during a discussion over lunch in the Athenaeum between Dr. FE Jones, then Managing Director of Mullard, and Sir Olliver Humphreys of GEC who realised that such a joint company could be a viable UK competitor to Texas Instruments, then the leading supplier of semiconductors in the UK. The resultant joint company was managed by Mullard and run by JA Jenkins, all the products being sold through Mullard with GEC receiving 1/3rd of the profits. For the several years of the existence of the joint company we sought to co-ordinate our semiconductor work

* *Alec was succeeded in this important task by John Fekete, who had done some excellent work on radar systems, John rightly took the job very seriously and made some valuable innovations. He was well regarded but left in 1989 to join Bruce Joyce in the Imperial College IRC and sadly died of cancer a few years later.*

with that of GEC Wembley and to agree our research objectives with them and with the production units in Stockport and Southampton. This we did through participation in a series of rather formal Research Co-ordination and Research Objective Meetings held in rotation at the various sites. It was a difficult time; GEC's approach to research was completely different from ours, they were strongly product-oriented but also heavily geared to CVD, (the Government Defence Department concerned with the funding of electronic devices) whereas we were more concerned with basic material problems, novel devices and fabrication techniques. For us the seeking of CVD support was an option, which we might choose to follow if there were evident advantages to our programme and interests in doing so. We were, however, left in no doubt as to which style Jimmy Jenkins preferred as he was always loud in his praise of the GEC men in their very successful efforts to secure CVD funding and rather dismissive of our more modest results. I, nevertheless, firmly believe that ours was the right approach. Nevertheless the GEC people with whom we had to deal were splendid; EG James, Dai Jones, Clive Foxell, Ralph Knott, Stan Bradshaw, and Bob Brander in Wembley and R(Dusty) Miller, Alan Foster and Alan Billingham in Stockport were all of outstanding technical competence and great characters with whom many of us formed lasting and valued friendships.

Although reasonably successful the joint Company broke up at the end of 1968 following GEC's acquisition of AEI and English Electric, companies having semiconductor activities which did not sit easily with the GEC share of ASM. The break up seemed very sudden and came as a surprise to us in MRL and also to our friends in Wembley, one of whom, Dai Jones, the only actual ASM employee there, found himself disposessed and evicted at three hours notice. They were hard men in GEC. At the break up Mullard bought the GEC holding in ASM and thereby acquired the Stockport factory which, by then, had moved from its decrepit premises in School Street to a beautiful new facility in Bramhall Lane, Hazel Grove. The product activities in Stockport were concerned with discrete power semiconductor devices and microwave semiconductors and the latter, particularly, depended critically on the research support it had received from Wembley. This, more or less overnight, became unavailable to them and so the decision was taken to set up microwave semiconductor device work in Salfords and to this end we set out successfully to recruit people from Wembley. Thus in 1969 we were joined by John Summers, Maurice Pierrepont, Ken Board, John Kerr and, later (though not for microwaves), by Stan Brotherton and Trevor Neill from Wembley (there may have been others whom I have forgotten).

It was quite an upheaval, and one which caused some difficulties for us within Concern Research as the French Laboratory, LEP, was considered to be the centre for microwave device work.

Several new facets of the Laboratory's interactions with the Product Groups were added when Philips acquired the Pye Group of Companies in 1968. Although aspects of this acquisition caused raised eyebrows in the Stock Market, Pye duly became part of Philips UK and we were confronted with several new technologically based companies with whom to develop effective contacts. These included Pye TVT, Pye TMC, Pye Unicam, Cathodeon Crystals and others. They all had great hopes of the Research Laboratory, some of which, in time, were fulfilled.

## THE PROGRAMME

Although during this period a greater emphasis developed on interdivisional programmes it is convenient to continue to discuss the highlights of the Laboratory programme under the headings of the four scientific divisions.

## THE SOLID STATE PHYSICS DIVISION

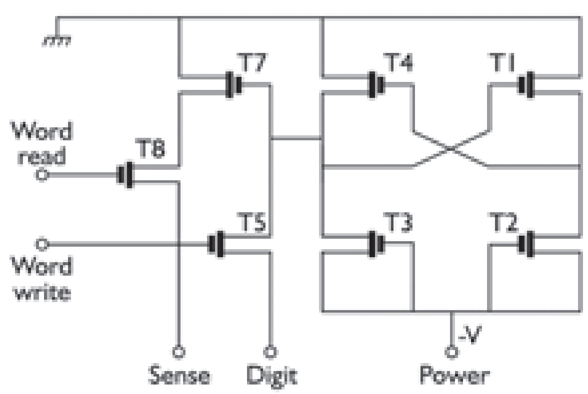
### The MOST Store and the ACTP.

It was at this time that the concept of the integrated circuit and a realisation of the enormous potential of this technology began to develop on a world-wide basis. It was obvious that MRL should seek to play a leading role in the development of the technology and to determine how best to address the question the Micro-electronics Working Party was set up. The members of this party included Kurt Hoselitz, Julian Beale, Graham Cripps, Ray Peacock and Steve Robinson and there may have been others. They were charged with considering the technology and suggesting a suitable vehicle for its development. Of the three or four targets, which they suggested, that selected was a 1024 bit static random access computer memory on a single semiconductor chip. This was a revolutionary concept as computer memories were then almost entirely based on magnetic cores or thin films.

Not entirely co-incidentally one of the shared cost civil initiatives launched by the British Government at this time was the Advanced Computer Technology Project (ACTP). This operated under the aegis of the new Ministry of Technology and we put forward our semiconductor memory project as part of the ACTP. The proposal was accepted and an

RSRE based co-ordinator appointed, this was Dr. G Perry, who was most helpful and supportive throughout the programme. Roy Parry (Mullard) of course had a leading role in obtaining this and other similar contracts.

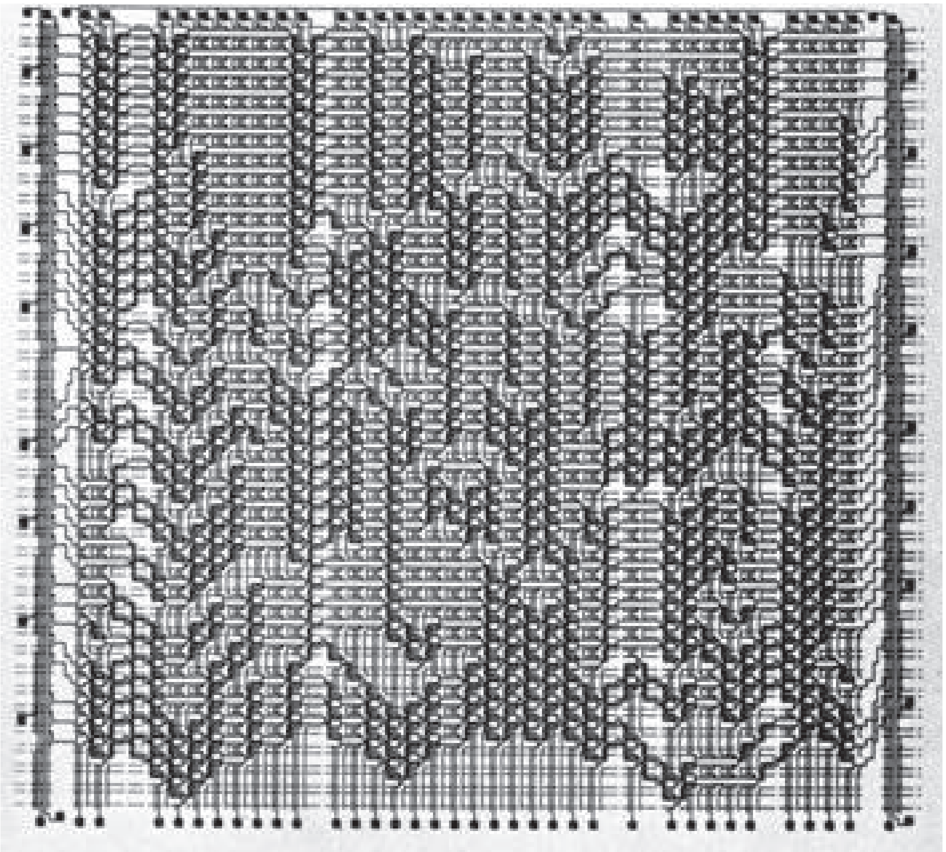
The project was necessarily interdivisional, the design of the chip and address circuitry being undertaken jointly in SSP and CPA, the chip fabrication in SSP and the machine to implement discretionary interconnection of the bits on the chip was designed in CPA and Engineering and made in the Engineering division. Discretionary interconnection calls for some explanation; it was considered necessary because we did not think that there was any realistic possibility of our making a chip containing an array of 32x32 binary bits, each containing seven MOS transistors, in which all the bits were viable. We therefore decided to make a 40x40 array, probe test each bit and interconnect the good ones to form the desired 32x32 array. It all seems a bit bizarre in the light of the technological capability of 2004 but represented the state of the art in the late 1960s.



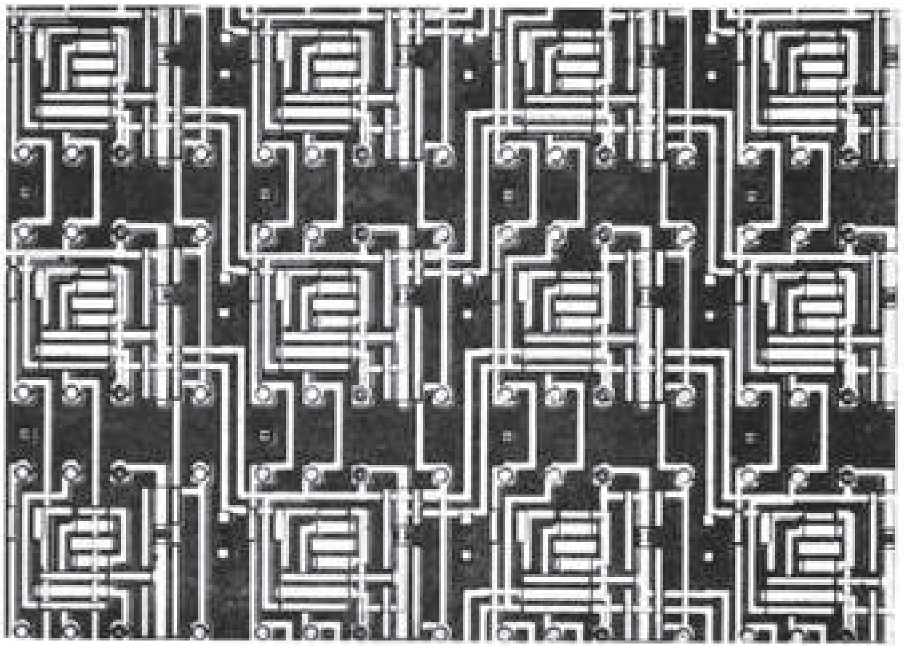

*The MOST store bit circuit*

The basic bit circuit employed seven P-MOSTs and is shown right, here the transistors T1-T4 form a normal bistable, T5 is used for setting the bit and T7 and T8 facilitate reading the state of the bit. The original thinking had been to fabricate the bit using complementary n and p MOSTS, a technology which offered advantages in respect of power consumption. Early on in the project, however, difficulties with this technology dictated the all p MOST approach. There were two levels of metallization on the chip separated by an oxide layer, the lower level provided the interconnections inside each bit, whilst probe pads, with contacts through to the lower level, were provided on the upper level. The final discretionary interconnection pattern was at the upper level. The bit circuit occupied an area of 250 x 250 $\mu m^2$ and was repeated in each direction at 300 $\mu$m. The silicon processing employed was largely conventional and was carried out in the Semiconductor Devices Section of SSP under the direction of Peter Daniel, with Andy Beer and Keith Nicholas each taking a major part. Harry Brockman and Ivor Stemp were responsible for the actual device processing. The figures overleaf show a complete discretionary interconnection pattern and details of the bit interconnection.

A programme for determining the discretionary interconnection pattern following



*Discretionary interconnection pattern*

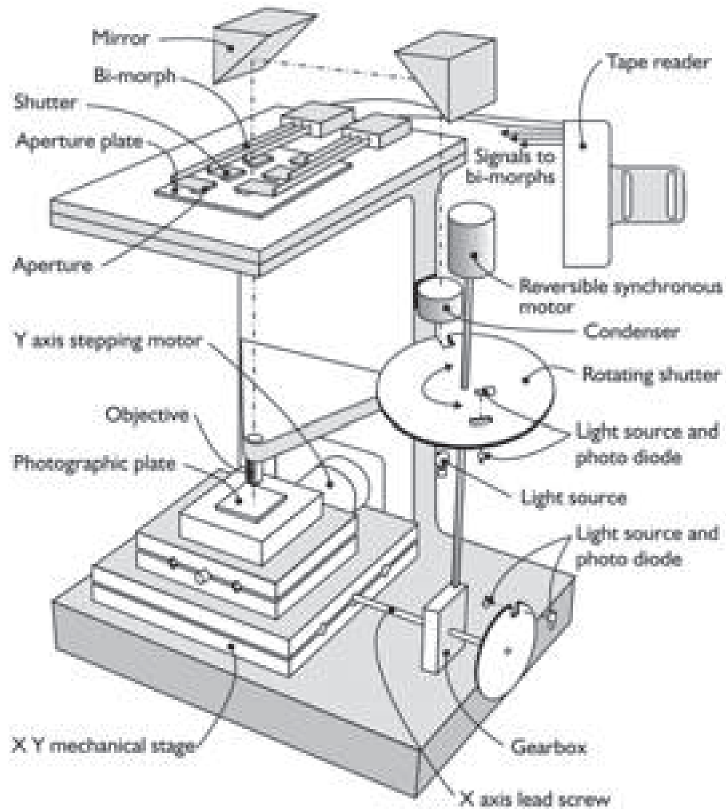


*Detail of the bit interconnection pattern*

probe testing of the chip was developed by David Parker in CPA and the machine for creating the discretionary wiring mask was designed by Peter Swift of CPA and Ian Lewin of the Engineering division and made in Engineering. It was essentially a block flasher, the necessary shutters being operated by means of piezo-electric bi-morphs. Although the machine had its teething problems it eventually worked satisfactorily and was further developed by Ian Lewin to provide a laboratory pattern generating service. One of the early versions of the machine was demonstrated to a large group of visitors in the course of one of the many progress meetings we had. Sadly it was driven too hard by its, perhaps, over optimistic inventor (Peter Swift) and the bi-morphs gave up in a spectacular pyrotechnic display! We believe that the visitors understood. A diagram of the machine is shown with a photograph of one of the later models

The use of the electron beam pattern generator, being worked on in VPD, to generate the interconnection masks was also explored at the time. This would have been the better way to go but, the Ministry preferred the opto-mechanical machine and the EBPG approach to the problem was not pursued.

In some ways this visionary project was ahead of its time. With the benefit of hindsight it is clear that it demanded a processing capability far beyond what we initially had available



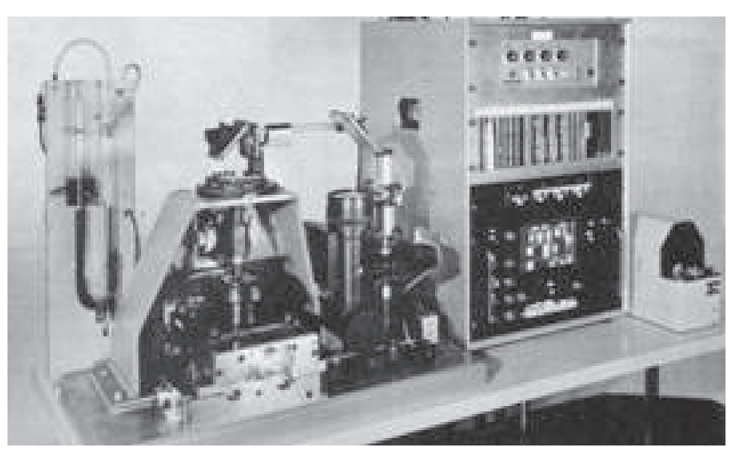
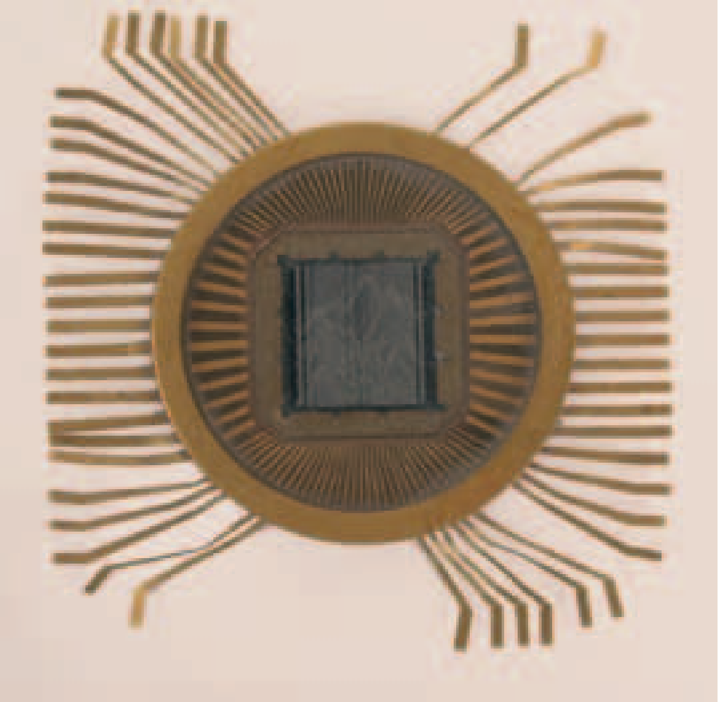



*Diagram of the Pattern Generator and photograph of Pattern generator*

in MRL. However a new laminar flow clean room was built in 1968 and this gave considerable improvement, the necessary yields of bits for interconnection of storage arrays being realised. The facilities still weren't adequate though and problems of continuity between the top and bottom metallization levels remained. These effectively precluded the realisation of full size interconnected arrays, and the project was terminated in 1970. This MOST store was, nevertheless, probably the first, working semiconductor random access memory in the world and helped to lay the foundations of the enormously developed semiconductor storage industry of today.



*A full size "discretionary wired" 1024 bit chip in its special mount (damaged)*

**Ion Implantation.**

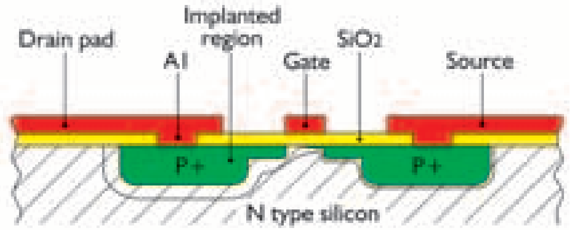
The established method of introducing dopant species into a semiconductor was by diffusion either from a contiguous solid sample containing the required species or from a gaseous environment at an elevated temperature. By its very nature diffusion is imprecise and the realisation of controlled doping profiles by diffusion a matter of some difficulty. In the mid-sixties interest began to develop in the possibility of introducing dopant species into a semiconductor by implanting high energy ions of the required element. There were two main difficulties with the technique; one was the need for complex and expensive machines with which to effect the implantation and the other was that the ion

bombardment produced substantial damage and generally the implanted ions were not, in the first place, electrically active.

Julian Beale, however, was interested in the technique and had some good ideas for exploiting its potential advantages. We therefore established a collaboration with AERE Harwell who were prepared to make their specialised machines, which were capable of effecting implantations, available for experiments. Amongst these were two isotope separators, developed in connection with the UK nuclear energy programme, which offered energies from 2keV to 200keV and ion currents of several hundred microamps of almost any desired species. Harwell charged £25 per hour for the use of these machines and in addition the users had access to Harwell luminaries such as Geoff Dearnaley, Harry Freeman, Jim Stephens, Stuart Nelson and, in the early days, Mike Thompson. What a resource! Beale and his collaborators, Keith Nicholas and, from 1967, John Shannon then worked together with AERE on implantation experiments and devised annealing schedules for silicon implanted with boron or phosphorus which produced sufficient electrical activity in the implanted layers without destroying the desired doping profiles.

Here then was a very powerful new process capable of being exploited in semiconductor devices and several important inventions resulted. Amongst these perhaps the two most significant were in MOST devices and were the following:-

1) The reduction of the gate to drain feedback capacitance by the technique of Autoregistration. Here an MOST is initially made by normal diffusion techniques but it is arranged that the metal gate electrode does not overlap either the source or drain regions. Then, using the gate electrode itself as a mask, boron (or phosphorus) ions are implanted through the oxide, which is 1000-2000 AU thick, to define extensions to the source and drain regions accurately with respect to the gate. A very substantial reduction in the gate to drain capacitance results with a consequent dramatic improvement in the high frequency performance of the device. An autoregistered MOST is shown .




*An autoregistered P-MOST*

2) The control of the threshold voltage of the MOST by implanting donors or acceptors in into the channel region. Among other things this technique enables the fabrication of depletion and enhancement devices with controlled threshold voltages on a single substrate.

The patents for these immensely important inventions are in the names of Julian Beale and John Shannon and owned by Mullard/Philips and the techniques are exploited under licence by the majority of integrated circuit manufacturers even today.

Despite the very real advantages offered by ion implantation, in the development of which the Laboratory had a pioneering role as we have seen, Mullard and Philips were frustratingly slow to exploit it. The product divisions were reluctant to interfere with their expensive production processes and waited for a lead from the US companies, which, of course, duly came. Work on ion implantation, though, continued in MRL and in 1969 a Danfysik implantation machine was purchased and installed in the laboratory in A Building formerly occupied by the Linear Accelerator. The erstwhile linac personnel, Gordon McGinty, Brian Goldsmith, Ron Thomas and Barry Martin operated the machine and undertook work on improving its performance. The team was moved from the Systems Division to VPD when the accelerator work was concluded in 1969.

**The Transluxor.**

One of the main factors limiting the high frequency performance of a bi-polar transistor is the transit time of carriers across the base. In 1965 Julian Beale and Peter Newman suggested that if a device could be made in which the signal were carried across the base by photons rather than charge carriers the base transit time would become negligible with a consequent improvement in the frequency performance. Also the base width could be increased giving a reduction in base resistance which was also beneficial. This was the Transluxor, it was decided to give it a try and a project team was assembled in the Semiconductor Physics section of which Newman was the leader. The device had an n-p-n structure with a GaAs emitter and base and a GaInAs collector. A crucial part of the project was the growth of the GaInAs/GaAs heterojunction collectors. Carole Fisher, Ewart Baldwin and Robin Hunt, initially using an alloying technique to make the heterojunctions and later vapour phase epitaxy, were mainly concerned with this very difficult work and had a measure of success. A vital factor in the functioning of the device was the efficiency of light generation by electron-hole recombination in the base. This needed to be close to unity and there were grounds for believing that it was although the Nat Lab, Hendrik Klasens in particular, never agreed. The principal problem in the construction of the device, however, was the collector where the lattice mismatch between GaAs and GaInAs made the growth of good quality GaInAs very difficult. It is interesting that the Government

establishments, through CVD, were sufficiently intrigued by the idea to place a RP contract with us.

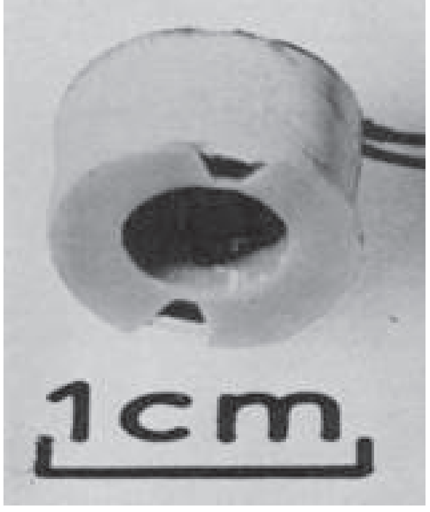
Although there were several occasions when it was thought that devices giving positive gain had been realised there was never a completely unambiguous demonstration and the project was terminated in March 1968. One of the factors influencing this decision was a careful theoretical appraisal of the device by John Slatter of CPA, John was very sound and he concluded, in his diffident, apologetic, style that the device could never deliver the performance hoped for it. Another cogent factor was the steady development of the high frequency performance of more conventional devices, in particular microwave MESFETS by Fairchild, Plessey and others, which greatly weakened arguments for continuing with the Transluxor. We learned a great deal from the exercise though with regard both to electroluminescence in III-V compounds and, particularly, vapour phase epitaxy of GaAs. This latter area developed quite significantly and we supplied high quality, well-controlled GaAs layers for microwave devices within MRL and to various concern device centres, in particular ASM Stockport.

*Mr. John Slatter*

In addition to the people already mentioned those involved at various times in the project included Hugh Wright, Geoff Allen, Trevor Tansley and Brian Tuck. None of these stayed in the Laboratory, Hugh Wright went to Plessey, Geoff Allen to Mullard House and Trevor Tansley and Brian Tuck entered the academic world where Brian eventually became Professor of Electrical Engineering in Nottingham. To my great personal regret Peter Newman left us in 1966 and went to the Plessey Laboratories in Caswell, subsequently joining Mackintosh Consultants. He was an ambitious man and I learned subsequently that he, not unreasonably in my view, had hoped to be appointed as SSP Divisional Head in succession to Kurt Hoselitz. In the event he was not and the appointment of Julian Beale as sub-divisional head, a new layer of management above him, must have made his promotion prospects in MRL seem very thin. Peter was leader of a large and important section and he was a serious loss to us. John Orton, one of the best physicists we ever had in the Laboratory replaced him, making a big change in subject area. John was, in his turn, replaced as leader of Quantum Electronics by David Paxman, another extremely able and versatile colleague.

**Magnetics.**

During this period work in the Magnetics area was very much concerned with magneto optic phenomena and their possible applications. Faraday rotation (the rotation of the plane of polarisation of a beam of plane polarised light as it traverses a magnetised medium) was extensively studied, theoretically and experimentally in Yttrium Iron Garnet ($Y_3Fe_5O_{12}$) and related materials. Compositions were developed in which the rotation was independent of temperature in the normal ambient range (-20C to +60C) and this coupled with the high transparency of the materials in the near infra red suggested a number of applications. Not the least of these was a simple low cost optical modulator capable of being used in the transmission of audio and video information on an infra-red carrier. An experimental model of such a modulator and its use in a simple communication system are shown here.




*IR communication system (left) being operated by Roger Cooper, Magneto optic IR modulator (right)*

Another potential use, which attracted interest from CEGB, was the use of the phenomenon to realise a contactless ammeter. The principle is simply that a piece of YIG (for example) placed on a conductor carrying a current is subject to a magnetic field and its state of magnetisation and hence the current in the conductor can be determined by

interrogation with an infra-red beam. The device had a current range of $10^{-3}$ to $10^{5}$ amperes and seemed to be very appropriate for the remote determination of the current in high voltage grid lines. A product activity aimed at exploiting the commercial potential of these magneto-optic devices was initiated in Mullard Southampton. Fred Harrison, Ron Pearson, Tony Crossley, Roger Cooper and Graham Lang were the principal participants in the magneto-optic work while John Page, with infinite and inimitable care, prepared the superb garnet crystals on which the work was based.

An on-going programme in magnetics for many years was that undertaken by John Knowles on magnetisation processes and loss mechanisms in ferrite materials. This involved detailed studies of domain wall movement in these materials and generally demanded experimental skill and insight into magnetic phenomena of the highest order. In this work Knowles co-operated closely with Eric Snelling in CPA and with the Mullard factory in Crossens.

**Chemistry and Other Things.**

Much of the Solid State work depended critically on knowledge of the precise structure and chemical composition of the materials being worked on for their own sake or exploited in devices. Often it was necessary to determine precisely the concentration of trace constituents such as dopant species in semiconductors and the chromium in synthetic ruby used in the maser work. This pushed analytical chemistry to the limits and demanded capability in sophisticated techniques such as:-

a) mass spectrometry for which we bought an AEI MS7,
b) scanning electron microscopy and electron probe microanalysis for which we had a combined JEOL instrument,
c) transmission electron microscopy (a Philips instrument) and
d) secondary ion mass spectrometry.

In addition there was more conventional wet chemistry and X-ray structural analysis.

Eric Millett, who headed up the Chemistry activity, knew what was required in this area and, unabashed by the capital investment called for, spared no effort in obtaining it. Although there were times when one wished chemistry and the chemists far enough, Eric was invariably right in these matters, and, largely as a result of his vision and determination, the Laboratory acquired an analytical facility which pretty well represented the state of the art

*Mr. Eric Millett*

*Dr. John Brice*

in the field. Within this there were several acknowledged experts who achieved national and international renown including :- Barry Clegg (Secondary Ion Mass Spectrometry), Jon Gowers (Transmission Electron Microscopy), Paul Fewster (X-Ray Structural Analysis), Mike Burgess (Scanning Electron Microscopy), John Roberts and Fred Grainger (Mass Spectrometry). With regard to material preparation, something of a vertical tradition had built up in the division, with each section looking after its own. This was not the most efficient way of operating and most bulk crystal growth was, in time, undertaken in John Brice's section where Brice was ably assisted by Peter Whipps, Peter Whiffen and Owen Hill among others. For various reasons the growth of crystals for the magnetic work remained outside this section. Epitaxial growth of compound semiconductors also moved to the Millett area following Peter Newman's departure.

The crystals grown in John Brice's facility included the following:-

- Yttrium Aluminium Garnet (YAG) which was popular in solid state lasers (we actually made a $Ho^{3+}$ in YAG 2μm laser).
- YGaG for work on Quantum Counters (a Quantum Electronic infrared detector), Lithium Niobate and Bismuth Silicon Oxide for Acoustic Surface wave filters (their use in TV IF systems was being explored in Systems and CPA).
- Potassium Tantalum Niobate (KTN) and Barium Strontium Niobate for electro optics and pyroelectrics applications in VPD and SSP together with various other pyroelectric materials for infrared detectors.

Some of these in particularly KTN, on which Peter Whipps did a remarkable job, were extremely difficult to prepare and demanded great skill, patience and dedication.

## THE CIRCUIT PHYSICS AND APPLICATIONS DIVISION

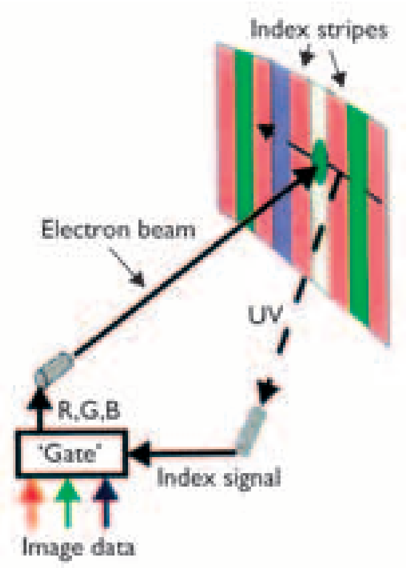
### The Beam Index Tube.

The search for an alternative colour TV display to the Shadowmask tube continued to be a matter of high priority in Philips and, following the Banana Tube project, interest focussed on a Philco invention, which became known as the Beam Index Tube.

In this tube the colour phosphors are deposited on the screen not in an array of dots as in the shadowmask tube but in an array of vertical lines containing the colour triplets interleaved with a pattern of lines containing a UV emitting phosphor. At its simplest there

is one UV phosphor line per triplet and, as the single electron beam is horizontally scanned, a UV signal is generated and detected providing an indication (index) of the position of the scanning beam in relation to the colour triplets. The attraction of the concept lay in the fact that it was a single gun system and that the UV indexing avoided the need for the complicated "dead reckoning" necessarily employed in the shadowmask tube. The system is illustrated in concept below. Ken Freeman points out that for this idea to work several conditions must be satisfied. Firstly the beam current must always be large enough to provide a reference signal and this means that a true black can never be produced. Secondly the reference signal must be free from image information - crosstalk - and lastly the spot size must always be small enough to hit only one stripe at a time, in order to avoid colour desaturation. To help with these problems black guard bands were inserted between the stripes.

Tubes of this type were made in the Nat Lab and MRL's role in this big Concern project was to find solutions to the problems of using the tube in a colour TV receiver. Cross talk proved to be a major problem but nevertheless working receivers were made following the implementation of various ingenious schemes to minimise the effects, in fact good pictures were obtained with 90° index tubes in 1968 sometime before the 90° shadowmask tubes appeared on the scene. There were, however, problems with the acceptability of the display largely centred around the visually intrusive stripe structure and the relatively poor contrast consequent upon the need for a continuous finite beam current. These problems could perhaps have been resolved but the need to follow the world trend towards larger deflection angles led to increasing difficulties with reliable indexing and colour saturation problems due to degraded spot size. These factors resulted in the project being terminated in 1969 but it had been a major activity in CPA for some six or seven years and in many ways extremely successful; interestingly the circuits devised were largely valve based. The principal participants were Ken Freeman, Richard Jackson and Dennis Rudd.

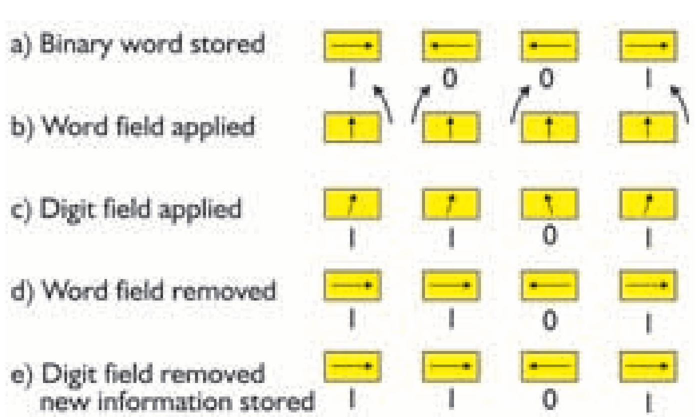



*Beam index tube concept*

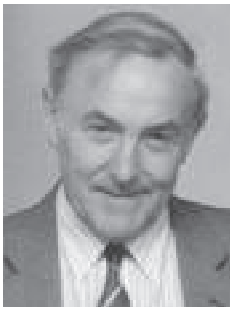
**The Magnetic Thin Film Store.**

In this period the demand for computer information storage systems, which was not great by today's standards, was almost entirely met by ferrite core stores. These consisted of arrays of ferrite toroids, each of which could be magnetised in either a clockwise or anticlockwise direction. This bi-stable property was necessary for the representation of information in binary form. The necessary magnetic fields could be applied to the cores, and flux changes in them detected, by wires passing through the toroids. Arrays of such cores, assembled by piling them vertically into stacks, were manufactured by the Mullard Company and formed an important part of the product range. The threading of the necessary wires in the core stores was very largely done manually and as, in the pursuit of higher speeds, the cores became smaller and smaller it became practically impossible.

The finding of a high speed alternative to the core store was then a matter of great importance to the Company and attention focussed on magnetic thin films. Earlier work in MRL in Charles Fuller's Thin Film section in SSP (and elsewhere) had indicated that small areas of evaporated NiFe alloy films containing about 80% nickel could exist as single magnetic domains. If a sufficiently strong magnetic field were applied during the deposition process the direction of magnetisation in the film elements could be parallel or antiparallel to the field. Here then was another two-state system but the crucial question was whether the direction of magnetisation could rapidly be reversed. The brute force technique, ie the direct application of a reverse field, would reverse the magnetisation but only slowly since, in this case, the reversal depended on domain wall movement through the film, a slow process. However, it was found that within these thin film elements the direction of magnetisation could be rotated very rapidly through 90$^{o}$ by applying a magnetic field (the word field) orthogonal to the preferred direction of magnetisation. Application of a second small field (the digit field), orthogonal to the word field, would tilt the magnetisation in one direction or the other, as required, and following removal of the word field the magnetisation would relax to its "target" state. This process is illustrated here. Although it seems complicated




*Orthogonal word address mode of storage*



*Mr. Ted Eilley*

*Dr. Ray Peacock*

the switching process is quick, being less than 100ns, and magnetic thin films apparently offered the desired high speed alternative to magnetic core stores.

A major project to demonstrate a magnetic thin film store was therefore established in CPA, initially under the leadership of Ray Peacock and later, Ted Eilley, and plans put in hand for a subsequent development in Mitcham. The immediate problem in MRL was the optimisation of the technique of evaporating the thin films of NiFe on to aluminium substrates, which also served as the ground plane of the strip lines used in addressing the arrays. This work was successful and, by the end of 1967, a small store was completed. This had 64 words each of 40 bits and had a cycle time of about 100ns; the magnetic elements in the store were rectangular 2mm x 1mm films of 80% NiFe. This success had a considerable impact and it was decided to proceed to the realisation of a 1Mbit store having a cycle time of less than 150ns. Ray Peacock transferred to Mitcham to head up the development programme whilst Ted Eilley became responsible for the MRL programme directed at the realisation of a research prototype. The Mitcham work was to be based on the Salfords experience and directed at the fabrication of a fully engineered production prototype. In 1968, however, Peacock was put in charge of the Microwave Division in Mitcham and left the project, having championed it with great vigour. Ted Eilley was then given overall charge of the whole project and was seconded to Mitcham for the purpose.

The realisation of a store containing one million working flat thin film elements in MRL called for the building of two major pieces of equipment. An evaporator capable of handling large batches was designed and built in the Engineering Division under the aegis of Ron Foster, Bob Maddox and Colin Overall. A complicating factor was that a uniform magnetic field had to be applied to the substrates during the evaporation of the films and this precluded the use of ferromagnetic materials in the machine. Despite these difficulties and the inevitable teething problems a satisfactory batch evaporator was built and brought into operation. A prototype of this machine is shown overleaf. The second essential machine was an automated tester able to exercise each element on a substrate and to measure the read output signal obtained from it. A large sequential digital logic system to accomplish this was designed and built, its output, on punched paper tape, being analysed and summarised, remotely, on the MRL computer. There were many problems. One was the sheer size of the array of thin film elements which occupied an area 1.5m square and much ingenuity went into compacting the element array and arranging the interfaces to the access circuits

*Mr. Ulrich Pick with a NiFe Film evaporator*

to minimise the volume. Another intractable difficulty was that the uniformity and performance of the thin film elements fell short of what was expected and needed with consequent serious signal to noise ratio problems. A third difficulty besetting the project team was an over rigid adherence to a system of project management imposed by Mitcham. This was a type of critical path analysis known as Project Evaluation and Review Technique (PERT). Although fine in a production activity, employing standard processes with no unknowns, it was less appropriate to a research activity. Despite the problems, the Company's conviction of the market opportunities never faltered and the development part of the project attracted UK Government funding under the ACTP. Thus the work went on in both Salfords and Mitcham but the difficulties with regard to the quality of the magnetic films persisted and therefore, first the Mitcham project was abandoned in favour of another approach and then in June 1969 the MRL project came to an end. It later emerged that the problem with the magnetic thin films was due to the effects of oxygen as a trace impurity in the film and that good layers could be realised if steps were taken to eliminate the oxygen. By that time however it had become inescapable that random access memories would be dominated by silicon integrated circuit technology, particularly the MOST technology and that any technology which was not silicon based was, even if it offered superb performance, effectively a non-starter. In addition to those we have mentioned the MRL staff involved with this project included Norman Richards, John B Hughes, David Lishman, Paul Hulyer, Eric Eves, John Marsh and Ulrich Pick.

An earlier computer store project undertaken in CPA had been based on a superconducting bi-stable element, the Cryotron, and this was terminated in 1966. It was a fascinating concept though and dear to the heart of Hendrik Casimir, who, prior to joining Philips had been professor of Physics in Leiden, the birthplace of low temperature physics and superconductivity, indeed his wife had some claim to having invented the Cryotron.

The "silicon rules, OK " creed had consequences for the SSP Thin Film Section as the arguments for continuing basic work on superconducting or magnetic thin films became very weak. The section was therefore re-directed to work on semiconductor integrated circuits, a major change which was not welcomed by many of the party several of whom chose to leave the Laboratory. Of these David Tilley joined Brian Ridley in the University of Essex, where he duly became a professor, Terry Clark eventually joined the University of Sussex and he too became a professor. Tony King and Graham Robinson joined my friend Peter Chester at that time Director of the Electricity Council's Laboratory in Capenhurst.

**Optical Character Recognition.**

The project on developing computer techniques for automatic character recognition had been running in the Systems division as part of the Electronics group for some years but in 1968 it transferred to the Circuit Physics Division within which it was a better fit. This was a demanding programme aimed at the development of techniques for the reading of characters from an uncontrolled source. The task was intrinsically very demanding of computer storage and logic capability and the challenge was the design of data processing routines which were feasible with the then current computer systems. The input to these early OCR machines was provided by a flying spot scanner. Together with the MOST Store and the Magnetic Thin Film work the OCR work attracted support from the Advanced Computer Technology Project (ACTP) MRL thus being one of the major centres of work in the project. This being so, progress meetings for the whole UK project were frequently held at MRL. These meetings were normally chaired by a member of the NPL, who were responsible for the management of the project. On one of these occasions those attending included a solitary and rather pregnant lady. In the course of the day Tony Weaver presented the MRL work on OCR with great clarity and enthusiasm, as was his wont. Following Tony's paper the chairman remarked that the essential content might be summarised by observing that "inside every fat character there is a thin character trying to get out" to which he added brightly "a thought that will, no doubt, commend itself to the lady member of the meeting". This maladroit pleasantry evoked embarrassed titters and will, I suspect, haunt him forever! I can't remember his name - he wasn't one of us.

An OCR machine based on the MRL work and able to recognise printed characters was developed by MEL and marketed under the Unidata label round about 1970. Only two or three were sold before the commercial activity came to a premature end with the collapse of Unidata - a consortium formed by Philips, Siemens and Bull to make and market computers and computer based systems. Research work in this general area however continued in the Laboratory the main participants being Tony Weaver, David Woollons and Peter Saraga. David Woollons left in the early 70s and pursued a University career.

## THE SYSTEMS DIVISION

**Parametric Amplifiers.**

The work on semiconductor parametric amplifiers continued and a notable achievement was the design and construction, between 1966 and 1968, of a cascaded diode

parametric amplifier system, having a bandwidth of 500MHz about a centre frequency of 4GHz with a noise temperature of less than 25K, for satellite communications.

In the actual device, a block schematic diagram of which is shown in the figure below, two cooled stages, separated by a low loss circulator and staggered in frequency, are followed by a wide band room temperature stage, with appropriate isolation - two circulators being necessary in this case. The liquid helium cooled stage provided a gain of

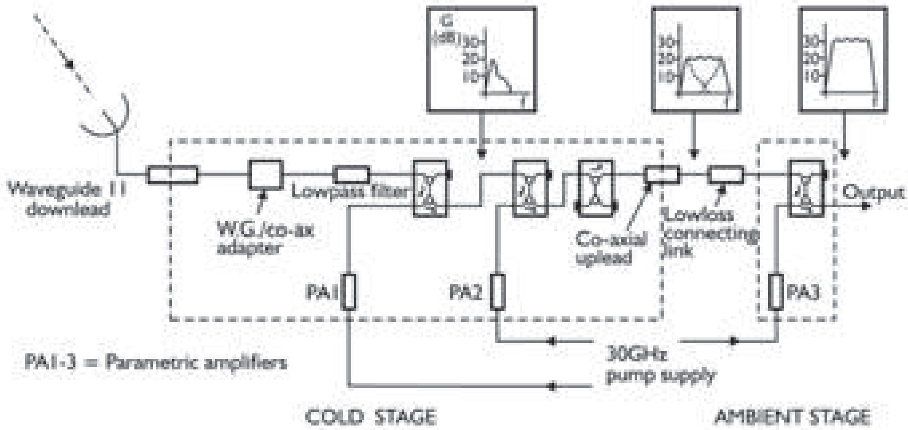
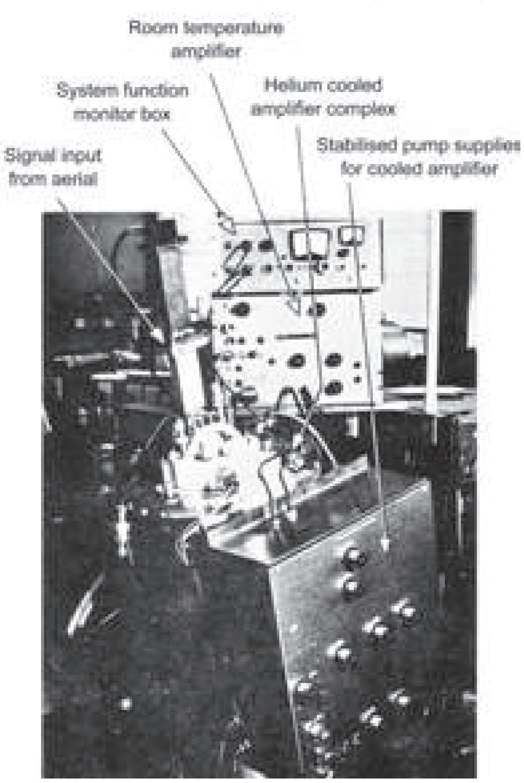



*Diagram of Amplifier complex*

20dB with a noise temperature of less than 20K over 500MHz and the room temperature stage gave a further 12dB adding only a few degrees to the total amplifier noise temperature. The diodes used in the amplifier were ASM gallium arsenide varactors and the technique of reactance compensation was employed to realise the large bandwidth. The devices had a co-axial configuration essentially as described in the previous chapter. It is interesting that the input waveguide to co-ax transformer, the low pass filter on the input (to exclude power from the ground station transmitter at 5.9 - 6.0GHz) and the circulators are all in the cooled environment in order to minimise the contribution to the noise temperature due to losses in these components. The system performed very well giving a gain of 31±2dB from 3.7 - 4.2 GHz with a noise temperature of less than 25K. The system is illustrated on the right.



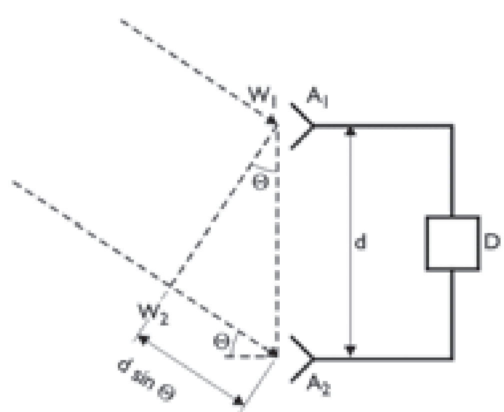

*Amplifier system*

This system was made under a contract from the GPO and was installed on the Goonhilly satellite ground station antenna in 1969 replacing the earlier maser amplifiers. It was installed in time for it to be used in the relaying of the pictures of the first Apollo Moon landings.

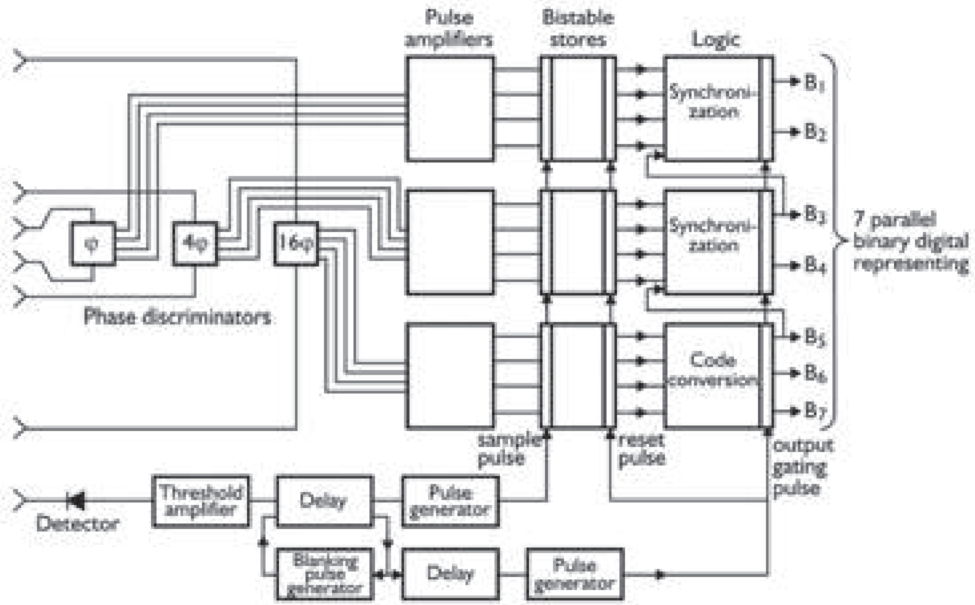
During 1968 the Laboratory's programme on solid state masers which had had such a dramatic and important part in the first satellite TV experiments was concluded with the construction and supply of a 7GHz maser system for military comsat applications. *Sic transit gloria mundi.*

**Microwave Systems - Radar.**

In Chapter 3 we discussed Steve Robinson's invention of the compact phase reversal hybrid junction and its application in instantaneous frequency measurement. In that case a measured phase change in a known length of transmission line is used to determine the frequency of an incoming signal. Similarly, having determined the frequency, the technique can be used to determine the phase difference between the signals received by two antennae separated by a known distance and hence the bearing of the source of the signal. The principle of this most elegant method of bearing determination is evident from the figure. To increase the accuracy of the measurement it is desirable to maximise the separation of the antennae but if the phase difference then becomes greater than 2π, ambiguities are introduced. These can however be resolved by comparison of the outputs from two (or more) interferometers with different spacing of the antennae. Thus during the period of this Chapter much effort was devoted in MRL to perfecting systems exploiting this concept and also, particularly by Robert Alcock and Peter East, to digitising the outputs. The diagram opposite shows a digital direction finder comprising three interferometers with spacings in the ratios 1:4:16. The three phase measurements are converted directly to digital form, amplified and processed to provide a measurement of bearing in binary code. The accuracy is that of the largest interferometer whilst the field of view is determined by the smallest, so we have, contrary to the well known law, the best of all worlds!.

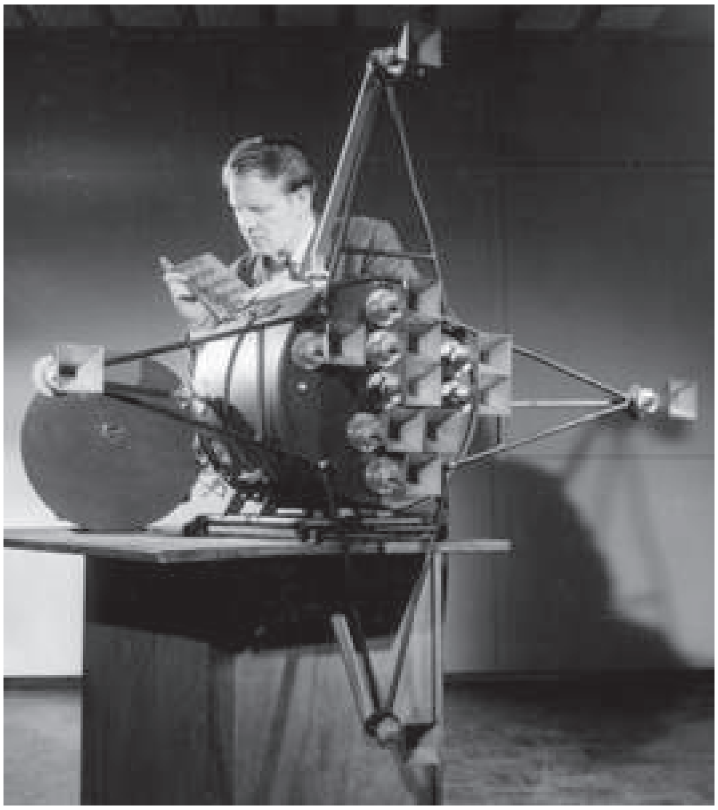



*Bearing measurement with an interferometer*




*Digital direction finder*

ESM systems exploiting the frequency/bearing correlation concept have proved to be enormously important and formed the basis of the Abbey Hill ESM system (Outfit UAA-1) which was developed by MEL and fitted in a very large number of ships of the Royal and US Navies. Peter East, who became Director of Advanced Development and Technology in Racal Defence Systems, comments that "IFM receivers based on the original MRL concept are now universally used operationally for wideband monitoring of radar environments in naval, airborne and ground-based ESM systems all over the world. Its importance is such that many countries have developed their own IFM



*Ray Johnstone with a experimental model direction finder*

*UAA-1 ESM operator's console*

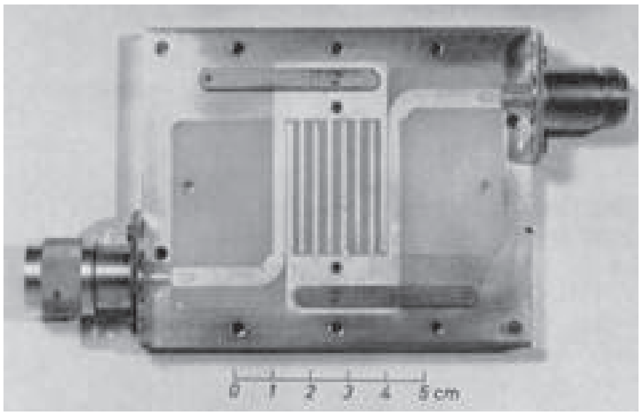
manufacturing capability with only minor architectural changes." A fairly recent version of the Abbey Hill system is shown here. It is difficult to exaggerate the importance and value of these inventions to the Concern and the Country.

Attempts to exploit these techniques in civil as well as military applications continued in MRL and amongst the former was the AVOID project, led with great flair and elan by Keith Fuller. This was a system for vehicle navigation, which provided a flicker free, perspective radar picture of a $40^{o}$ sector in front of the vehicle to which it was fitted. The system could detect small obstacles including pedestrians and had a range of about 200 metres. Although it attracted interest from the Board of Trade and the British Airports Authority it was not commercially developed. A digital guidance equipment for aircraft, MADGE, however, was another story to which we will return in the next Chapter.

**Microwave Filters.**

During this period there was an interesting programme of work in the Systems division on microwave filters. This was master-minded by Ralf Levy who, regrettably, didn't stay very long in MRL but was very successful in designing and making a range of filters using strip line techniques. These mainly took the form of transmission line filters formed in a double comb configuration (ie interdigital) essentially a broadband filter, or in a single comb. The pass band of the latter is determined by the capacitive loading at the free end of the comb fingers. An interdigital filter resulting from this programme is illustrated. There are obvious relationships between this work and that undertaken ten years earlier in VPL on backward wave tubes, which used interdigital structures and, later, that on travelling wave masers which used comb structures. Sadly the opportunity for a synergistic interaction was not

taken as Levy seemed unaware of the earlier work and I certainly hadn't caught up with the Systems work. There was a great security consciousness in Systems division, which tended to make them rather secretive about all their microwave work, classified or not. However, I wish that I'd thought of making a strip line comb, in the Levy style, deposited on the ruby used in the TWM!



*An Interdigital filter*

**Chromatography.**

In 1966 a new programme on Gas Chromatography was started in Systems division in support of a Philips product activity in MEL and a number of specialist staff including Dr. W Miller and Dr. FW (Eric) Wilmott were recruited for the purpose. Over the years the programme developed rather successfully particularly in the development of pyrolysers and computerised output systems.

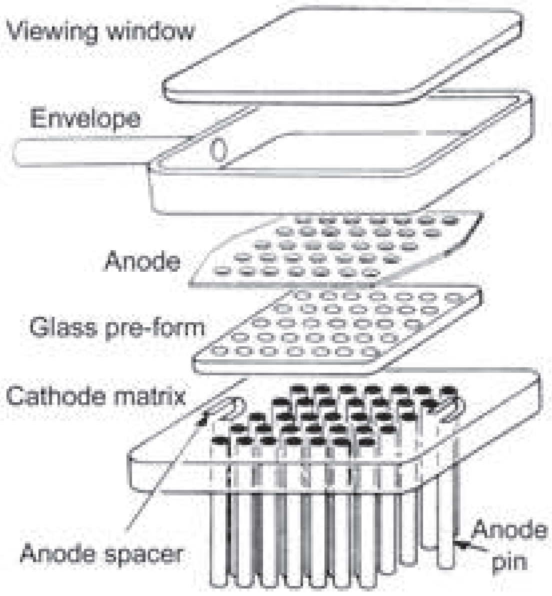
Following the acquisition of the Pye Companies in 1968 the relevant product activity became that of Pye Unicam and the programme was re-oriented accordingly.

## THE VACUUM PHYSICS DIVISION

**Matrix Display Tubes.**

Numerical indicator tubes formed an important part of the Mullard product range in this period. The conventional design, the Nixie tube, incorporated ten glow discharge cathode electrodes, formed as numerals, stacked one behind another or, more subtly, a seven bar array. The latter demanded more complex address circuitry and was thus much more expensive to apply in the days before integrated circuits.

An alternative approach was to simplify the design of the discharge tube in order to offset the costs of the coding circuitry and here George Weston and Ray Hall together with the Glass shop technicians made an important advance. They devised a 7x5 dot matrix array in which the elements of the array were formed by the tube foot pins, the potential difficulties caused by sputtering from the pins being avoided by recessing them below the surface of the glass base. In this situation sputtered material was trapped within the recess and thus leakage between the pins and blackening of the viewing window was prevented.




*Matrix tube construction*

This was a very important advance and the rather simple construction of the matrix tube is illustrated.

This design was a world first and the device rapidly went into production in the Mitcham factory in 1971 as the ZM 1251.

Keith Johnson of Circuit Physics devised a TTL* based cross bar method of addressing quite large arrays of these tubes, George Weston and Ray Hall being pictured here with one of these displays.

The possibility of making display panels, employing arrays of such recessed cathode elements, possibly as large as 30cm square was envisaged at the time but uses other than alpha-numeric displays do not seem to have been


*George Watson and Ray Hall (right) with the matrix tube display*

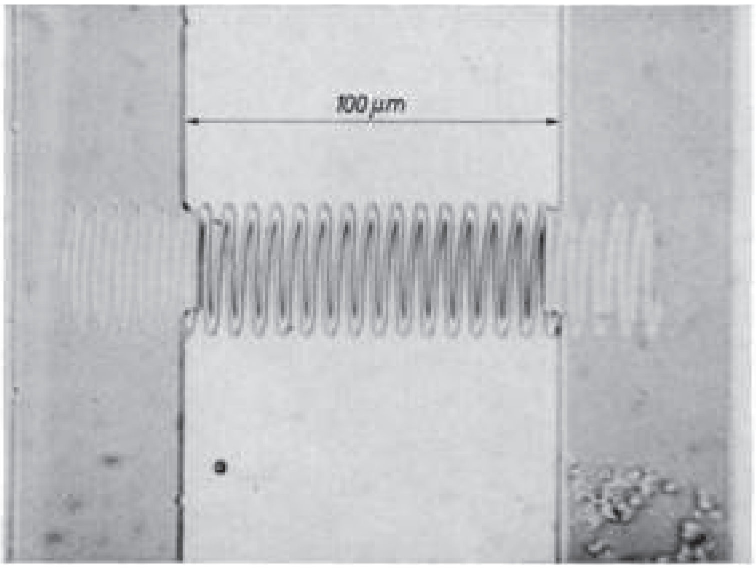
* *Transistor Transistor Logic a series of integrated circuits marketed by Mullard at that time.*

considered. Eventually the device found itself in competition with LEDs and here it was at a disadvantage because of its relatively high drive voltage requirements. Notwithstanding, it survived for many years and this is an interesting example of the Laboratory's giving the Mullard Company a world lead in an important product area.

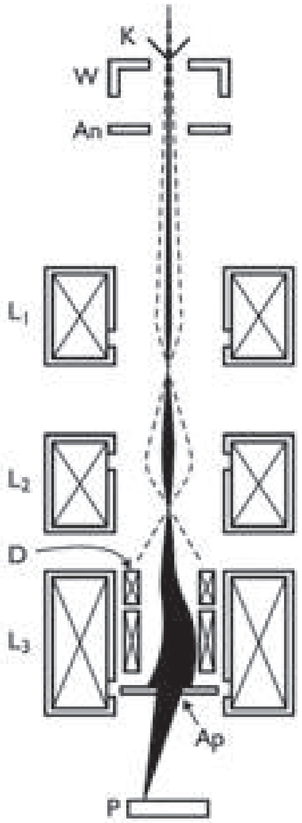
**Electron Beam Pattern Generation.**

One of the most important projects undertaken in the Laboratory had its origins in this period. This was the use of electron beams in micro-electronics and one of the first applications pursued by Nick King and his team in VPD was to use a finely focussed electron beam to deposit a high resolution silica diffusion barrier on silicon. This was achieved by introducing tetraethyloxysilane vapour into the work chamber of a high resolution electron beam machine, the vapour condensed on the silicon surface and was dissociated by the electron beam to form $SiO_2$. Although not completely pure this oxide served as a satisfactory diffusion barrier and enabled the realisation of MOST devices having a source-drain separation of 1μm. The structure of the device is illustrated in the photo below and a schematic diagram of the machine configuration is shown on the right.

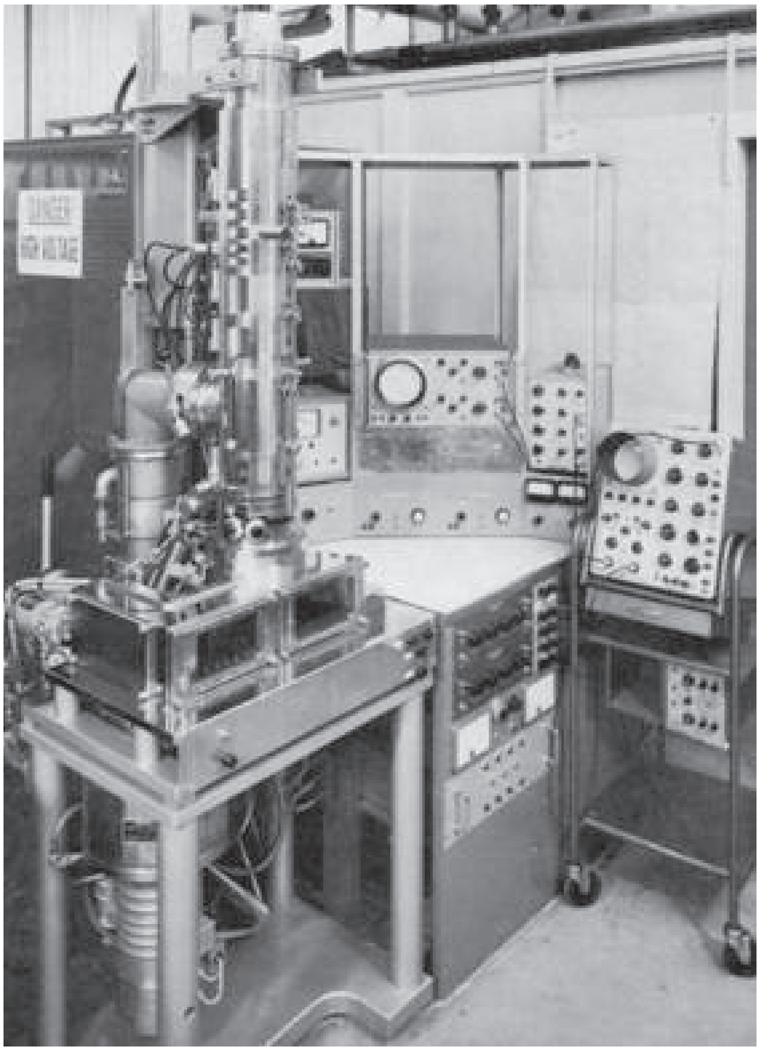
The electron beam machine itself is illustrated overleaf, and towards the end of this period a machine similar to this was successfully operated under computer control to expose electron sensitive resist in order to




*Electron beam deposited diffusion barrier for an MOST*




*Schmatic of Electron Beam Pattern Generator*



*Electron Beam Pattern generator*

produce the arrays of patterns required for integrated circuit masks. The machine employed a 2μm diameter 15kV beam which could be scanned over an area 38x38mm. Gold markers 100μm square pre-deposited at intervals on the substrate provided positional information for the computer control system and masks with 2μm resolution could be written in about twenty minutes.

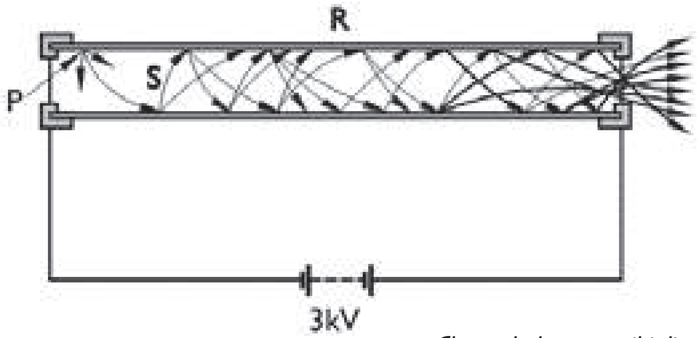
This work, which was carried out primarily by Nick himself, Jim Beasley, John Kelly and Mike Underhill (seconded from the Systems division), marked the beginning of the use of automated electron beam machines in the generation of masks for the fabrication of integrated circuits. The work was to develop greatly in future years and was destined to place Philips in a world leading position in the manufacture of Electron Beam Pattern Generators.

**The Channel Electron Multiplier and Channel Plates.**

An invention of great importance and, outwardly at least, elegant simplicity, was the channel multiplier which was developed at this time in Vacuum Physics by Brian Manley and his collaborators, notably John Adams, Andrew Guest and Richard Holmshaw.

The device derives conceptually from the dynode structure and its associated resistor chain used in conventional photomultiplier tubes. It consists of a glass tube, having a length some fifty to one hundred times its internal diameter, the inside surface of which is coated with

a semi-insulating layer the end to end resistance being between $10^9$ and $10^{11}$ ohms. The device, which is illustrated here, operates in vacuum (in space applications the environmental vacuum is adequate) with a potential difference of about 3kV between the ends. Energetic particles or radiation entering the tube at the low potential end strike the channel wall liberating electrons. These are accelerated down the tube striking the wall and producing secondary electrons. The process continues until the electron stream finally emerges from the high potential end of the tube. The gain of the device depends on the applied voltage and the length to diameter ratio but not on the absolute dimensions; the maximum gain achievable was about $3x10^8$ (85dB). Single channel devices of this kind found application in space exploration experiments, in particular those conducted from the Mullard Space Science Laboratory by Prof Sir Robert Boyd FRS concerned, inter alia, with the measurement of soft X-ray emissions from the solar corona. This photgraph taken from one of Robert Boyd's notes, shows one of the channel multiplier devices. It is curved to prevent positive ions, generated by electron collisions with residual gas atoms, being accelerated back down the tube to the input, liberating electrons from the walls en route and thereby creating spurious pulses. The devices were marketed as the Mullard B310L.




*Channel electron miltiplier*

*Channel multiplier used in space exploration*

Since the channel multiplier could be scaled in size without loss of performance it was possible to make arrays of parallel small multipliers to detect two dimensional information and to produce images. Channel plates, as they were called, were proposed for use in astronomical soft X-ray telescopes and in diagnostic X-ray devices. The detection efficiency

of the device was, however, very high for low energy electrons. This led naturally to the consideration of the application of channel plates in display systems. Perhaps the most important of these was mentioned in the previous chapter in connection with Night Vision systems where the channel plate was exploited to great advantage to amplify the initial photocurrent and produce a high brightness visible display in a remarkably compact device. A serious effort was also made to use the channel plate concept in the realisation of a flat TV display, the Falcon Tube, which we will discuss in a later chapter.

**THE END OF AN ERA**

A sad event in the history of the Laboratory, which took place in 1966 was the death of Mr. SS Eriks KBE. He had retired, through ill-health, in 1962, his place as Chairman of the UK Group Board of Management being taken by Mr. JP Engels and Dr. FE Jones became Managing Director of Mullard Ltd. Although Mr. Eriks' visits to the Laboratory were rare indeed it was his vision for the Mullard Company which led to the foundation of the Laboratory in 1946. He was the father of the Laboratory.

A number of important staff changes took place during this time, some have already been mentioned but in addition we should note several others. George Taylor retired as Head of the Engineering Division at the end of 1967 and was succeeded in that demanding role by Peter Bunn. In April 1968 VI (Vic) Paynter was appointed as Personnel Manager in succession to Alan Ahern who moved to Philips Croydon and in October 1969 Fred Harrison took up the new function of Staff Development Officer to the Laboratories. Also in 1969 FO (Bunny) Munns retired as Chief Accountant being succeeded by John Day, who transferred from ASM Southampton. At the end of 1968 Brian Manley was appointed as Commercial Manager of the Mullard Special Tubes Division in Mitcham. This appointment eventually led on to a most distinguished career in UK Philips in the course of which Brian became a member of the UK Group Board of Management and a Director of Philips Industries Ltd., including the Research Laboratory amongst his responsiblities. To the great pleasure of us all, he was appointed FREng in 1984 and a CBE ten years later.

Pieter Schagen was appointed an Honorary OBE in March 1968 in recognition of his remarkable contribution to Defence Electronics through his work on image converters and night vision systems.

The most significant change, however, was that which took place in June 1969 when Peter Trier relinquished his responsibilities as Director of the Laboratories following his

*Handover of MRL by Peter Trier to Kurt Hoselitz*

appointment as a member of the UK Group Board of Management, with the formal title of Group Director of Research and Development, Philips Industries. His contribution to the development of the Laboratory was enormous. More than any other individual he had shaped the Laboratory, established its national and international reputation and achieved its integration within Philips Research. In the course of his subsequent career within Philips and to our great pleasure and satisfaction he was appointed FREng in 1978 and a CBE in 1980. A further award, which explicitly

*The translation of Kurt Hoselitz and Peter Trier*

recognised his contribution to Industrial Research Management and gave Peter particular pleasure, was that of the Glazebrook Medal and Prize of the Institute of Physics in 1984. Peter Trier was succeeded as Director by Kurt Hoselitz, their joint translation being the occasion for a great ceremony in the Laboratory, which is illustrated.

This was indeed the end of an era, Peter Trier was a great loss. Nevertheless the end of one era was the dawn of another and we looked forward with optimism to the Hoselitz years which lay ahead.

## CHAPTER FIVE

# THE HOSELITZ YEARS 1970 - 1976

### A NEW DIRECTOR FOR MRL

The Laboratory thus entered the eighth decade of the twentieth century with a new Director, Kurt Hoselitz. Within the UK the Director reported to the newly appointed Group Director of Research, Peter Trier, and within the Philips Concern to the member of the Board of Management (Raad van Bestuur) having responsibility for Research who was then Professor Hendrik Casimir, shortly to be succeeded by Dr. Eduard Pannenborg.

*Dr. Kurt Hoselitz*

Both Peter Trier and Kurt Hoselitz were extremely able but whereas Peter's style was analytical, careful and considered, Kurt was much more intuitive, quick and impulsive. Peter Trier never made a statement concerning the Laboratory in any forum without carefully weighing its meaning and assessing possible inferences which might be drawn from it. Kurt Hoselitz, on the other hand, would frequently say what he thought as he thought it, which could be a bit disconcerting. Peter Trier's way of working coupled with his substantial external responsibilities resulted, during his later years, in his "not showing his face enough in the Laboratory", as he himself put it. Kurt Hoselitz, however, considered this to be his first priority and indeed may well have been a more familiar figure around the laboratories and workshops during his incumbency than were the Divisional Heads. Another big difference between the two lay in their attitude to Government support. Peter Trier, rooted in the founding traditions of the Laboratory, regarded it as being of great importance in that it gave access to the expertise in the Government Laboratories and that it could open up substantial market opportunities, which would otherwise be closed to us. This, of course, was particularly true in the Systems area where the ESM work had created a huge world market. Hoselitz, doubtless thinking more of device work than systems, tended to regard Government supported projects as a

distraction arguing that the work resulted at best in very limited markets for esoteric devices thus tying up scarce resources to little effect. There were undoubtedly instances where this was very much the case, underlining the importance of critical consideration of the projects for which Government support was to be sought.

A major external change, which took place in this period, was the retirement in 1972 of Dr. FE Jones as Managing Director of Mullard Ltd and Chairman of Associated Semiconductor Manufacturers. A Fellow of the Royal Society and the holder of many academic honours FE was the ultimate technocrat; he was always keenly interested in the technical base of the Company and a strong supporter of MRL. His successor was Mr. Jack Akerman whose background was entirely commercial, however whilst Jack did not take the same direct interest in the technical work of the Laboratories as had his predecessor he recognised its value and was generally friendly and supportive.

**Laboratory Organisation.**

In mid 1970 David Allen who had headed the Vacuum Physics Division since its inception, decided that he wished to further his career in Philips outside Research and accepted a managerial appointment in Mitcham. To prepare for this though he undertook assignments in Blackburn, Eindhoven and Heerlen and did not take up his Mitcham role until 1971.Some years later he was appointed as Technical Director in MEL. David had spent twenty years in MRL and had played a major part in its development, he was a discerning scientist, an understanding and supportive colleague, never ruffled, a splendid cricketer and a great gentleman. He was succeeded as Head of the Vacuum Physics Division by his outstanding deputy, Dr. Pieter Schagen. In September 1970 John Brunskill, joined Philips Industries Ltd in Hanover Square and was replaced as Plant Manager by Arthur Jenkinson from SSP, this was a very shrewd appointment on the part of the new Director. Julian Beale and Steve Robinson were appointed Scientific Advisers to the Laboratory early in 1970 and Steve received a well-deserved OBE in the 1971 New Year Honours List. He left MRL in January 1972 to join MEL as Chief Commercial Engineer. Steve had made an enormous contribution to the work of the Laboratory and went on to pursue a most distinguished career becoming Product Director of MEL Ltd., Managing Director of Pye TVT Ltd., and finally Director of the MoD Royal Signals and Radar Establishment, Great Malvern, from 1989 to 1991. He was elected FRS in 1976 and FREng in 1980. Cliff Braybrook,

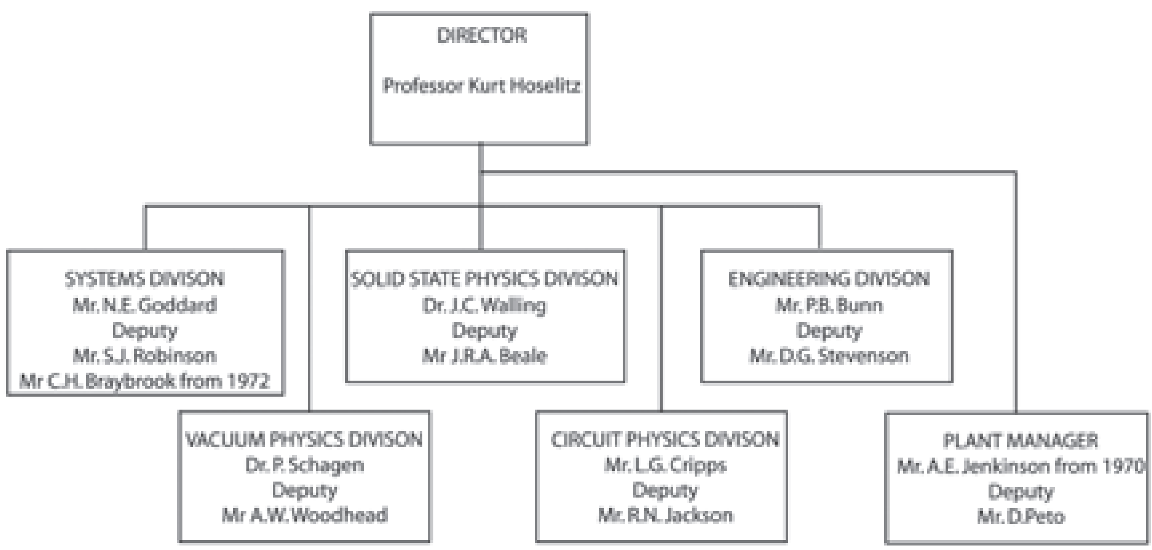
*Mr. David Allen*

*Dr. Pieter Schagen*

one of the founder members of the Laboratory, succeeded Steve as Deputy Divisional Head of the Systems Division.

In May 1969 the third of the Eastbourne Conferences took place and a number of important decisions regarding the organisation of the Laboratory were made and these were implemented in 1970. Most notably the sub-divisions and the sections within them were replaced by Groups, smaller than the sub-divisions but larger than the sections. This reduction in the number of managerial levels made it necessary to formulate and implement an overt scientific and technical staff structure, which was not dissimilar to that of the Scientific Civil Service. We thus had Scientists, Senior Scientists, Principal Scientists, Senior Principal Scientists (rare indeed) and Scientific Advisers (even rarer) with a similar, but less extended, structure for the Technical Staff. Not surprisingly these levels related directly to the established, covert, grade structure.

At the beginning of 1970 then we had the following organisation:-




Within the Divisions there were Groups as follows:-

**Systems:**

| | |
|---|---|
| Microwave Systems: | Mr. KL Fuller |
| Microwave Techniques: | Mr. CS Aitchison |
| | Dr. RB Davies from Dec 1972 |
| Communications: | Mr. JS Palfreeman |
| Electronics: | Mr. CH Braybrook |
| Chromatography: | Dr. W Miller |

**Vacuum Physics**

| | |
|---|---|
| Electron and Ion Beams | Mr. HNG King |
| Gas Discharges | Mr. GF Weston |
| Imaging Devices | Mr. AA Turnbull |
| Image Intensifiers | Mr. AW Woodhead |

**Circuit Physics**

| | |
|---|---|
| Automotive | Mr. DR Skoyles |
| Ferrites and Piezoelectrics | Mr. EC Snelling |
| Computer Techniques | Mr. ES Eilley |

(This Group changed its emphasis and name in 1972 to Telephone Techniques)

| | |
|---|---|
| Computer Applications | Mr. JA Weaver |
| ICs and Display | Mr. RN Jackson |

**Solid State Physics**

| | |
|---|---|
| ICs and Techniques | Dr. PJ Daniel |
| SC Physics and Microwaves | Dr. JW Orton |
| Magnetics and Ferroelectrics | Dr. RF Pearson |
| Materials | Mr. EJ Millett |

**Engineering**

| | |
|---|---|
| Design Department | Mr. DG Stevenson |
| Drawing Office | Mr. ST Hussey |
| Workshops | Mr. Vic Fry |
| Technology Department | Mr. RV Jeanes |

The support functions continued with Administration under Mr. J Day, Purchasing under Mr. J J Seymour (Pat Pleasance having joined MEL), Personnel under Mr. VI Paynter, Staff Development under Dr. FW Harrison and Maintenance under Mr. J Wood (Terry O'Donoghue having retired).

Inevitably there were changes in the structure and personnel and some of the most notable were the following:- John Orton transferred to VPD in order to strengthen the activity on 3-5 Photocathodes. He took up this appointment in 1974 having spent a year as

Visiting Professor in the Technical University of Eindhoven and was succeeded as a Group Leader in SSP by John Shannon. Colin Aitchison was appointed Reader in Microwave Electronics at Chelsea College in December 1972 and was succeeded as Group Leader in Systems by Dr. Bob Davies. The Chromatography Group became part of the SSP Materials Group in 1973. Also in 1973 Fred Harrison joined the Philips UK Central Personnel Department and Jim Basterfield of SSP took his place as Staff Development Officer, Vic Paynter left in 1973 and Mike Malpass succeeded him as Personnel Manager.

In May 1973 Norman Goddard was formally appointed Deputy Director of the Laboratories, retaining his responsibility for the Systems Division.

**Programme Planning.**

During this period the programme planning procedure evolved further with the formation of nine specialist programme panels to advise the PPC on project proposals, progress on existing projects and the state of the art in their particular areas. The programme panels dealt with Imaging, Silicon Devices, Telephony, Television, Radio, Display, Radar and Navigation, Computer Projects and Laboratory Technical Services.

Generally this proved to be a very successful arrangement as the panels greatly reduced the amount of spade work which the members of the PPC had to do, enabling them to devote more time to the consideration of the overall programme strategy and balance. This way of working continued for many years although as the programme changed the programme panels changed. It was a sound method of operating and was good for morale as people at all levels felt to some extent involved in the planning of the programme.

The Laboratory's interactions with other parts of the Concern, both formal and informal, strengthened during these years, a notable feature being the growing importance of the Concern Research Bureau. Based in the Nat Lab, and at this time headed by Prof Dr. JH van Santen, this group supported the International Research Co-ordinator, monitored the interactions with the Product Groups and undertook an annual review of the programmes in each of the Concern Laboratories. This was quite a formal event and members of the Bureau went through the planned programmes very critically. Membership of the Bureau was drawn, in part, on a rotating basis from the various labs and it was something of an honour to be invited to join. Several MRL people including Derek Andrew, Peter Green and Neil Bird were at various times members of the Bureau. It could provide a springboard for a distinguished career in the Concern and indeed I first met

Dr. SA (George) van Houten, later to become a member of the Raad van Bestuur, when he was in the Bureau.

**The Laboratory Advisory Council.**

In 1972 Kurt Hoselitz set up the Laboratory Advisory Council. This consisted of the most senior managers of the UK operating companies and was intended to assist the Laboratory Management to take proper account of the aims and capabilities of the UK Philips Companies in determining Laboratory policies with regard to programming, factory assistance, staff development etc. The members included the UK Philips Director of Research, The Managing Director and Technical Directors of Mullard Ltd., MEL, Pye TMC, Pye Unicam and at least one other Pye company. It was a high level meeting and generally positive and fairly helpful, whilst they were often critical they were pleased to have the opportunity of visiting the Lab, commenting on what was being done and pointing out the needs of the UK group. The MRL membership of this meeting was limited to the Director himself and the Deputy Director, which was appropriate as the purpose of the meeting was to advise the Director.

**Visitors to MRL.**

In common with all research establishments MRL had a continuous stream of visitors including the company's customers, other members of Philips UK and overseas, Government representatives, potential employees and our peers in academia, industry and research establishments world wide with whom we wished to exchange views.

*Visit of the Duke of Kent 10th July 1973*

In this period the Laboratory had its only Royal visitor, the Duke of Kent, who arrived on 10th July 1973 in a helicopter of the Queen's Flight, which landed in the grounds. He lunched with us and toured the establishment asking a number of what I thought were quite penetrating questions – he'd certainly done his homework. The Duke is pictured discussing ion implantation with Gordon McGinty the group including, Kurt Hoselitz and Peter Daniel.

Other eminent visitors to the Laboratory over the years were several Presidents and Vice Presidents of the Philips Concern. In addition to Mr Otten whose visit in 1959 we have already mentioned there were Frits Philips himself who spent a day with us in 1963 and is pictured here in discussion with Nick King, Dr. N Rodenburg, who visited in May 1975, and Dr. Wisse Dekker who made two or three visits whilst he was Chairman of the UK Group Board prior to becoming President. Dr. Th van Tromp also visited during the 60s when he was Vice President and Dr. Eduard Pannenborg too was a frequent and welcome visitor.

*Mr. Frits Philips in discussion with Nick King and a pensive Peter Tier*

Another notable visit of a somewhat different nature was that by the Directors of the Bell Telephone Laboratories which took place in February 1970 as part of the negotiations concerning the renewal of the crucial patent and cross-licensing agreements between Philips and Western Electric. Their purpose was to assess our capability and achievements and they were very serious about it. The party included, as I recall it, Jack Morton, Ian Ross (who later became President of BTL), AM Clogston, NB Hannay and W Boyd. They seemed to be sufficiently well satisfied as the agreements were renewed.

Another important group was that of the Exchange visitors from other parts of the Concern who spent periods of the order of a year working in the Laboratory. In the main, but not exclusively, they were members of the Nat Lab in Eindhoven and the visits were

very valuable both in terms of the direct technical benefit which resulted and the strengthening of the links between the Laboratories. There were, of course, reciprocal visits by MRL staff to other Philips Laboratories, for example John Shannon and Alex Stark each spent a year in Briarcliffe (USA) during 1970/71. Amongst the Nat Lab exchange visitors to SSP in these times were Frits Hooge (who later became Rector Magnificus of the Eindhoven Technical University), Pieter Severin, Broese van Groenou, Gerard van Gurp, Anton van Vijfeken, Kees Bulthuis and Bertus Pals. Bertus was in MRL during 1973 working on deep level transient spectroscopy of semiconductors and returned to the Laboratory in 1988 as a Divisional Head. Kees, who became the Philips International Research Co-ordinator in 1988 was with us in 1968 and was concerned with ion implantation. I think that he enjoyed the work but he found the fact he had to share a small office and did not have technical staff specifically assigned to him rather irksome. He gave me a fairly hard time and my situation was not helped by the fact that Mr. E Hoeksma, then Technical Director of Mullard Ltd was his uncle. Kees used to grumble about his lot to Uncle Hooky, who, I believe thought it all a huge joke. He was a very nice man, but nevertheless retailed the stories to Peter Trier, a fellow member of the Mullard Board. Always very sensitive to the way the Dutchmen perceived his Laboratory, Peter sought remedial action but there was nothing much that I could do – that was how we were! All part of the rich tapestry of life I suppose.

Hoselitz attached great importance to extended visits by academics, and visitors to SSP in the sixties and seventies included an American, Dr. Phil Flanders who worked in the Magnetics party with Ron Pearson and was a great success. He still keeps in touch with some of his ex-MRL friends and regards his time in MRL as one of the most valuable formative experiences of his life. There was also Professor Mula Shtrikman from the Weizmann Institute in Israel, a great friend of Hoselitz and another magnetics expert*. His visit, extending over several months was rather successful but a subsequent one by a truculent post doctoral Israeli most certainly was not and we called a halt to the Israeli visits, to the great relief of those concerned with Laboratory security.

* *Mula Shtrikman was a great character. He had been employed by Philips in Eindhoven from 1952-54, subsequently returning to Israel. Every year he used to send a crate of Jaffa oranges (once it was Avocadoes!) to his friends in MRL and other laboratories which he had visited. He died, after a long illness in November 2003.*

## THE PROGRAMME

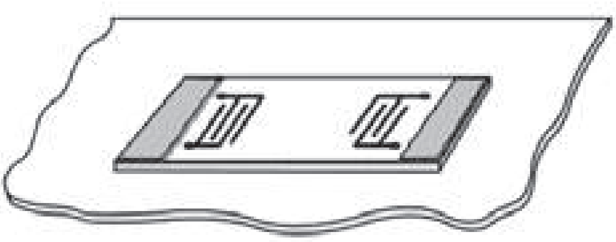
### CIRCUIT PHYSICS AND APPLICATIONS DIVISION

**Acoustic Surface Wave Devices.**

One of the besetting problems in the early days of integrated circuits was that of integration of the inductors necessary for the realisation of frequency selective elements. A viable solution to the selectivity problem was afforded by exploiting the properties of acoustic surface waves on piezoelectric substrates. Work in this area was carried out in MRL not only in CPA but also in Systems, SSP and Engineering and was, in fact, started in SSP in the sixties by Julian Beale and Ron Pratt. Beale's interest in surface waves developed in the course of an extended visit which he made in the early sixties to the IBM Research Laboratories in Yorktown Heights NY as part of a Philips IBM exchange scheme.

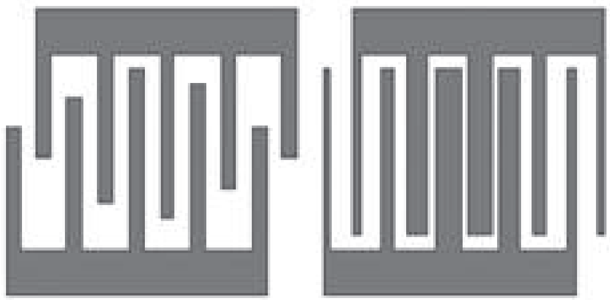
*Mr. Ron Pratt*

Surface waves on liquid media are very familiar but the fact that they can also exist on solids was not recognised until 1885 when Lord Rayleigh predicted them theoretically – they are sometimes called Rayleigh waves. The attractive features of the waves to the electronic engineer are that they are largely non-dispersive, essentially confined to the surface of the solid on which they propagate and have short wavelengths, leading to small devices. They can be generated (and detected) by an interdigital transducer structure deposited on the surface of the piezoelectric substrate, the elements of the transducer structure being several wavelengths long and spaced at approximately half the surface wavelength corresponding to the frequency of interest. A surface wave filter can be made with one such transducer for launching and a second for detecting the wave. The filter characteristic is determined by the frequency responses of the two transducers and is essentially their product. Such a filter is shown schematically here.

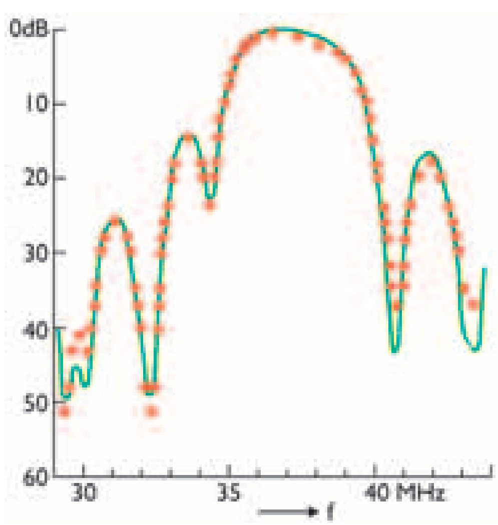


*Schematic of an ASW filter*

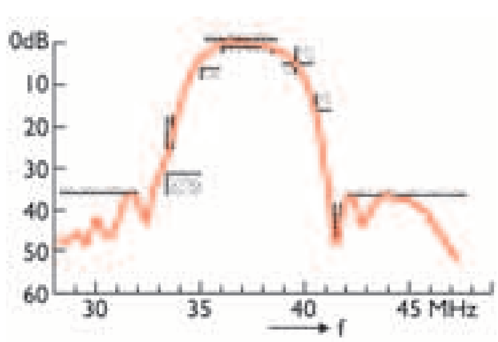
The calculation of the frequency response of a transducer of this type taking proper account of the elastic and piezoelectric anisotropy of the substrate and the periodic loading of the surface by the electrode structure is a matter of great difficulty and may well be impossible. At MRL though it was found that an adequate design procedure resulted from treating each element of the transducer structure as a source of surface waves and adjusting



*Source Weighting*




*Calculated and observed transmission characterisitic of a width weighted acoustic surface wave filter*




*Frequency response of an ASW TV IF filter*

(or weighting) the source strengths of the elements to achieve a required response curve. The source weighting was achieved by varying either the length or the width of the electrodes as illustrated. When various additional subtleties such as diffraction effects and source interactions were included the model worked remarkably well and in the figure theory and experiment for a width weighted acoustic wave filter are compared.

Ken Moulding and David Parker of CPA, Rick Mitchell, Eileen Read and John Palfreeman of Systems and Tony Crossley of SSP were all very much involved with developing the design procedures for these ASW devices. The frequency response of an acoustic surface wave television IF filter compared with the specification limits is illustrated. This was a complete device mounted in an integrated circuit package with its own preamplifier. These devices were compact, and stable requiring no in situ adjustments.

Narrow band ASW filters, some with response characteristics virtually unattainable by conventional techniques, were designed and made by John Palfreeman, Fred Smith, Bob Milsom and others in the Systems division with CVD support for radar applications and were completely successful, replacing conventional IF systems in several radar equipments.

The ideal substrate materials for ASW devices were considered to be single crystal piezoelectrics because of their great uniformity, reproducibilty, stability and freedom from ageing effects. Ceramic materials were cheaper but tended to be porous, less reproducible and less stable with respect to temperature and time. Much effort was

*Dr. Rick Mitchell*

therefore expended in SSP by John Brice and his colleagues, Tim Bruton, Owen Hill, Peter Whipps and Peter Whiffen on the growth of large single crystals of Bismuth Silicon Oxide (particularly) and its Germanium analogue as well as Lithium Niobate. Ted Curran, Louis Karr and John Meyer of the Engineering Division were concerned with the alignment, cutting and polishing of the substrates and with the deposition of the electrode structure.

Altogether this was a major interdivisional activity which involved a large number of people over a period of several years. MRL was unquestionably one of the world's pre-eminent centres, possibly the world leaders, in the field of acoustic surface waves and their applications. It would be nice to record that a successful product activity resulted from the programme but although Mullard started activities in Southampton and Mitcham these seemed to be rather half hearted and the decision was eventually taken to buy the devices from an outside supplier.

**The Gyrator.**

Another entirely different approach to the realisation of integratable selective circuits for television IF filters which was extensively worked on in MRL during this period was the use of gyrator circuits. Integrated chips were realised containing four gyrators (88 transistors in total) which functioned satisfactorily as television IF filter circuits. This work was carried out by Ken Moulding, John Canning, Paul Rankin, Roger Jones, John Wade and others.

**Telephony.**

In 1971 the it was decided that the Laboratory should discontinue work specifically concerned with computer technology and accordingly programmes in the Computer Techniques Group such as that on the MOST store were wound up. Within the Group however there was substantial expertise on digital circuitry and, following extensive discussions within the Concern it was decided that the Telephony area was one which offered important and demanding opportunities for the exploitation of that expertise. The name of the Computer Techniques Group was changed to the Telephone Techniques Group and a new programme was developed.

The rationale for this move was that, whilst for many years Philips, through PTI and Pye TMC, had enjoyed a strong position in long haul, high capacity telephone transmission

systems using frequency division multiplexing (FDM)*, that position was coming under threat as a consequence of the increasing use of digital techniques in telephony. A major factor in this digital revolution was the realisation that the technique of pulse code modulation (PCM) proposed in 1937 by Alec Harley-Reeves of STC could be made a practical reality by the use of integrated circuit technology which was being developed primarily for computer applications.

Some essential background to the use of digital techniques in telephony is the following. Nyquist's sampling theorem states that a bandwidth limited analogue signal can be represented virtually perfectly if the signal is sampled at a frequency of twice the bandwidth. A speech signal is considered to have a bandwidth of about 3kHz (300Hz to 3,400Hz) and thus, in principle, might be represented by a sequence of pulses resulting from sampling at around 6kHz. Practical considerations, however, dictate the use of a higher sampling frequency and in telephony 8kHz has become the standard. The magnitude of the sampled pulses is quantized (logarithmically) and represented by an eight digit binary number, seven digits indicating the level and the eighth the sign. A digitised telephone channel is then a bit stream of 64kb/s in each direction. Simply replacing an analogue channel by a digital one offers very little advantage but the digital approach allows the use of time division multiplexing (TDM) and it is possible to multiplex up to 30 channels, forming a bit stream of 2Mb/s. In those parts of the telephone network which employed loaded medium length wire pair cables carrying just one circuit per pair capacity could thus be increased by 15 times. (Not 30 times because the digital system required two wire pairs per circuit – one for each direction of transmission).

The move to digital systems thus resulted in some increase in system capacity but, more importantly, the use of solid state digital switching techniques, rather than the electromechanical Strowger systems, resulted in improved reliability, quality and speed, substantially reduced size and lower power consumption. Such a move was then crucial to Philips' business interests and lead to the involvement of MRL in this new and demanding area. Other arguments for mounting a telephony research programme in MRL were concerned with the need of Pye TMC for research support and the importance of establishing links with the British Post Office, then probably the strongest European operator. An advanced and very ambitious project was formulated in discussions with PTI Hilversum/Huizen and was to be concerned with the definition and proof of the design parameters of cable and terminal equipment for a 560Mb/s digital transmission system using

* *An important factor in the strong Philips position in FDM systems was the quality of the ferrite cores used in the necessary filters; the work of Eric Snelling in MRL over many years in this field contributed greatly to this.*

9 mm air-spaced coaxial cable. Staff were seconded to Huizen to get up to speed on critical aspects and Tom Hargreaves (of Huizen and MEL) was seconded to MRL.

This was an extremely demanding project with essentially three aspects to it. In the first place the system parameters had to be established within the constraints imposed by, among other things, the need to make use of existing transmission networks. This dictated the cable to be used and the spacing of the necessary regenerators. The design and construction of the regenerators formed the second major strand of the project whilst the third was concerned with the realisation of the high speed multiplexers and demultiplexers, in particular the 4 x 140Mb/s final multiplex. The need to supply power to the regenerators along the cable and to provide means of extracting a clock signal imposed additional problems. A further difficulty arose as a consequence of the unavoidable, frequency dependent ohmic losses in the cable; this demanded the provision of analogue equalisation as a precursor to the digital regeneration of the signal. The design of the multiplexer/demultiplexer was directed at the minimisation of the amount of circuitry running at the full bit rate. With this in mind John Hughes together with Bernard Coughlin of SSP and colleagues in the Nat Lab Integrated Circuit Atelier designed a small integrated circuit in a beam leaded, air isolated bipolar technology which achieved the final 4 x 140 Mb/s multiplex.

There were many other problems but they were all solved and a trial system was demonstrated and the results handed over to PTI. Sadly, this outstanding piece of work, carried out by Ted Eilley, John B Hughes, Norman Richards, Brian Gibson and John Hale with the support of Colin Overall and Ken Day in Engineering, did not result in a major new commercial activity. This was largely a consequence of the dramatic slow down in the world economy resulting from the 1973 oil crisis. Nevertheless some 560Mb/s systems based on the MRL work were sold by PTI to the Swiss.

**Satellite Television.**

In the early part of this period an extensive study was undertaken, largely in CPA, of systems and receiving techniques for 12GHz colour TV signals from geo-stationary satellites. Operation at such frequencies was a new departure for television at that time but geo-stationary satellites able to accommodate kilowatt transmitters and attitude stabilised antennae were evidently feasible so the study and an evaluation of the possible consequences for the industry was timely. The largely paper study was backed up by some

experimental work on the 12GHz systems and the photograph below, shows work on a model system which was subsequently demonstrated at the IEE. The paper describing the work by Ken Freeman, Richard Jackson, Peter Mothersole (then with Pye TVT) and Steve Robinson was presented at the IEE in May 1970 and later was awarded the Blumlein, Brown-Willans Premium. As a result of this work the Laboratory was able to make considerable input to the subsequent EBU/CCIR studies of feasible systems, broadcasting standards and receiver techniques for such direct satellite transmission.

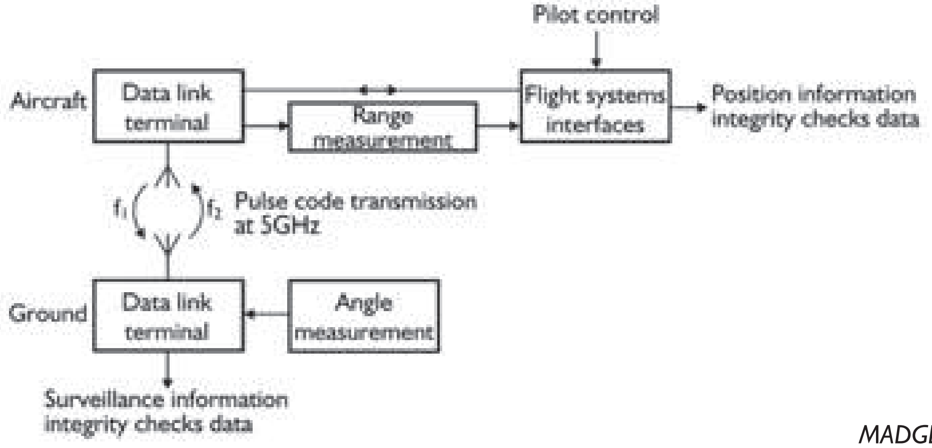
*Richard Jackson and Ken Freeman with the satellite system*

## THE SYSTEMS DIVISION

### MADGE

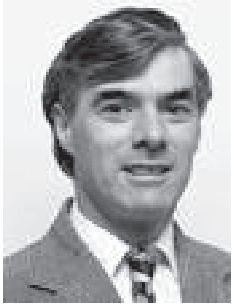
Work on Radar Systems continued to form an important part of the programme of the Laboratory and in this period the most significant activity was that on the portable military navigation system MADGE – Microwave Digital Guidance Equipment. This was an aircraft landing aid capable of guiding various types of aircraft to confined landing sites in poor weather. Interest in such systems was a consequence of the installation inflexibility of the then standard Instrument Landing System (ILS) and the growing use of helicopters and V/STOL aircraft particularly in the military sphere but also in business and industrial applications. There was thus a need for both transportable equipment for use at temporary landing sites and a low cost aid suitable for installation at secondary airfields. MADGE was designed and built in MRL to meet this need and was further developed by the MEL Equipment Company together with RAE - the Royal Aircraft Establishment.

The basic information required both at the landing site and in the aircraft was range, elevation and azimuth angles of the aircraft with respect to the landing site and additional data concerning, for example, ground topography, could also usefully be made available to the pilot. A schematic representation of the system is shown below. A two way microwave data link (5GHz) transferred information on azimuth and elevation, measured on the ground, and range, measured in the aircraft, between the air and ground stations. A vital component in the system was the digital interferometer, which was developed (as a private venture) at MRL and which we discussed in the previous chapter. Three such interferometers were used in MADGE, one to provide the elevation data and the other two




*MADGE system schematic*

*MADGE system in operation*



*Mr. Richard Vincent*

*Mr. Peter East*

for azimuth determination as can be seen from the photograph, (In some situations, apparently, two were used in the elevation measurements and one for azimuth).
In operation the measurement of both angle and range was initiated by transmission from the aircraft of a digital interrogation "word" prior to being addressed in this way all the ground stations were quiescent, an important factor from the point of view of security.

The system was completely successful and was judged the winner of a NATO competition, which took place in Fréjus in 1971. It was developed and marketed by MEL and entered service in the British Armed Forces in 1976.

The MRL staff primarily concerned with MADGE were Richard Vincent, Robert Alcock, Adrian Lucas, Tim Tozer and Peter East while Steve Robinson was actively involved in the work at MEL.

**MIRANDA and TOMCAT.**

Other Radar systems were developed in this period and included those with the code names of MIRANDA and TOMCAT.

MIRANDA was a vehicle based microwave receiving and signal processing system for the interception and analysis of pulsed radar transmissions. It was semi-automatic and was able to measure frequency, direction and pulse shape of incoming pulses in the range 1.5 – 4.5 GHz. It invoked a digital version of the Robinson IFM system for frequency

determination and a highly directional aerial for bearing measurements. It was very fast and able to cope with a dense signal environment in which there was a complex mixture of strong and weak signals. Peter East and others including Alan Dadds, Tony Lambell, David Body and Bill Burns were concerned with this project.

TOMCAT was an aircraft landing system based on MADGE (Time Ordered Madge for Civil AircrafT) which was developed for the French Philips Company TRT. The system was supplied to the French Government and was used in a submission of a landing system to the International Civil Aviation Organisation.

These examples serve to indicate how productive and valuable was the area of microwave and radar systems work made accessible by the invention of instantaneous frequency measurement system and the digital interferometer.

**Frequency Synthesisers.**

A notable achievement in Systems during this period was Mike Underhill's development of a range of digital frequency synthesisers. Two symposia were held to make the techniques familiar within the Concern. Both TDS and Elcoma successfully adopted these modular circuits.

**THE SOLID STATE PHYSICS DIVISION**

**III-V Compound Epitaxy and the Beginning of MBE.**

Vapour phase epitaxial growth of III-V compounds, Gallium Arsenide in particular, was undertaken in the Materials Group of SSP over several years. It was essentially in support of the microwave device work in progress in SSP and the photocathode work in VPD; layers were also supplied to Mullard Hazel Grove (Stockport) and within Concern Research (LEP primarily). Much of the work was supported by the Government through DCVD and members of the Group, Brian Easton, Carole Fisher and occasionally Eric Millett, took part in the meetings of the UK GaAs Consortium which was organised by DCVD. Meticulous care was necessary if material of good and reproducible quality was to be realised and the Group established an excellent reputation in this field. Indeed I remember one meeting with CVD when we were awarded a contract for a demanding Q-band Gunn device (VX6538) on the strict understanding that Carole was to grow the necessary GaAs layers.

*Mr. Brian Easton*

*Miss Carole Fisher*

*Dr. Bruce Joyce*

*Dr. Tom Foxon*

*Mr. Jim Neave*

At the beginning of this period something of a stir was caused in the UK microwave device world as a result of a claim emanating from RRE Malvern that the transferred electron effect giving rise to a negative resistance, in Indium Phosphide proceeded by a different mechanism from that in Gallium Arsenide. This, it was suggested, would result in devices made in InP having superior efficiency and power output to those of GaAs devices and such devices were also considered unlikely to exhibit the dipole domains observed in GaAs which cause the Gunn effect (cf Ch 3). This was exciting stuff and the UK device community, with active encouragement from CVD, turned its attention to InP. MRL took part in this and David Paxman made some early measurements on bulk InP devices which suggested that there might be something in the ideas; certainly high efficiency devices were made in the material. In addition to the device work a project on the growth of InP by liquid phase epitaxy was successfully undertaken in the Materials Group by Colin Wood employing a novel capillary plate technique. As the InP work progressed, however, the suspicion grew in MRL that the material wasn't really very different from GaAs. We thought that, contrary to the RRE expectations, we had seen evidence for domain formation in the material and this was confirmed by careful measurements made in the Nat Lab by Gerard Acket. There didn't then seem to be much point in continuing to work on the material and, rather to the chagrin of CVD and the RRE advocates of the material we pulled out of what Kurt Hoselitz scathingly described as the Indium Phosphide Adventure.

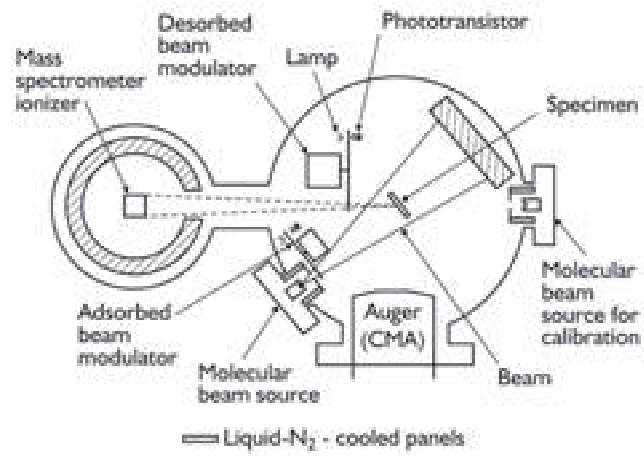
Work on Gallium Arsenide vapour phase epitaxy however continued and took a new turn when Bruce Joyce began to take an interest. Bruce had joined MRL in 1969 having previously worked at the Allen Clark Research Centre – the Plessey Laboratory - at Caswell. Although not initially involved with the epitaxy work, his first task at MRL being concerned with the Si-$SiO_2$ interface, Bruce* suggested that it might be possible to study the complex chemical kinetics of the VPE process by using modulated molecular beam techniques. The VPE process depended on the reduction on the substrate surface of the chlorides of Gallium and Arsenic by hydrogen. The chemistry was complex and difficult, being further complicated by the fluid dynamics involved in the transport of the molecular precursors to the surface. It was thought that the processes might be elucidated by the use of molecular beams of the chloride precursors. It seemed a good idea and the proposal was approved but before the project began Al Cho and John Arthur at Bell Labs

* *We should note that Bruce Joyce was the orginator of the Molecular Beam Epitaxy process having developed the technique for silicon whilst he was at the Plessey Laboratories.*

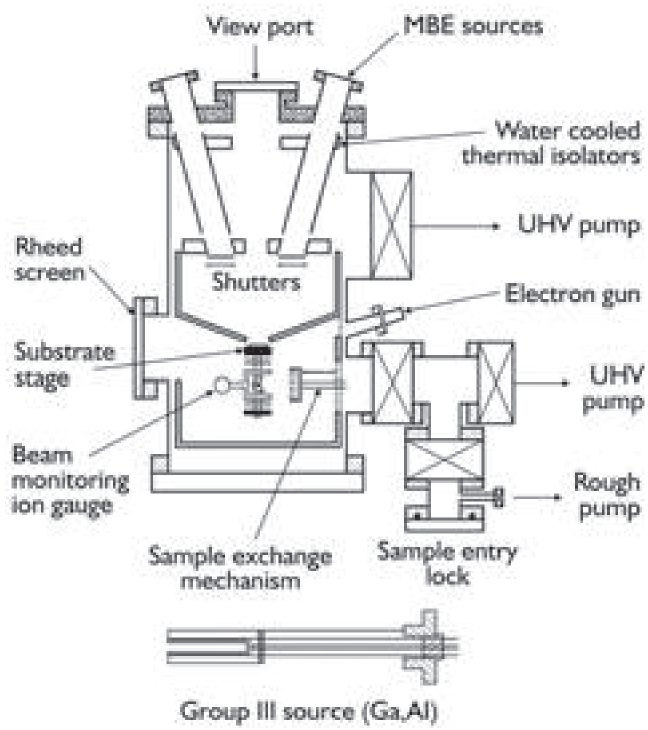
published a paper showing that epitaxial GaAs films could be grown directly from elemental sources by using molecular beams of Ga and $As_4$ (arsenic evaporates in this form). This put rather a different complexion on things; the investigation of the chloride process was set aside, and the efforts of Bruce Joyce and his team (Tom Foxon, Jim Neave and, a little later, Mike Boudry) were devoted to the study of the elemental beam system and its possibilities for the growth of layer structures in compound semiconductors.

This was the beginning of the Laboratory's programme on molecular beam epitaxy, which was to continue for many years, the Laboratory becoming one of the world's leading centres in this field. Kurt Hoselitz, whilst recognising the elegance of the technique, was initially doubtful of its applications potential. On the other hand Hendrik Casimir, discussing the technique during what was probably one of his last visits to MRL, was greatly intrigued by the possibilities and gave the activity his strong support – no bad thing!

The early work undertaken was concerned with evaporation and surface chemistry studies using modulated beam mass spectrometry and in a series of beautiful experiments Bruce and his collaborators succeeded in establishing kinetic growth models which remain valid today. Also, and most importantly, they established the conditions under which the growth takes place in a two dimensional fashion, that is, such that one molecular layer is complete before the growth of the next commences. It is this characteristic which makes the technique ideally suited to the




*Modulated beam experiment*




*An MBE growth system*

growth of low dimensional structures. The apparatus used is illustrated here. The work benefited considerably from the experience of the Materials Group in interfacing analytical equipment such as mass spectrometers to computers. This was before the days of PCs and laptops and the computer controlled experiments had to be carried out through direct links to a mainframe machine. Mike Boudry provided the computer system know-how and it is fair to say that without the computer the control of the experiments and the extraction and reduction of the data would probably have been impossible. Here we must acknowledge the vision of Eric Millett who, very early on, recognised the importance of using computers in analytical instrumentation and successfully established these facilities in his Group. Equipment for MBE growth of layers was built and high quality material for microwave FETs was supplied to LEP during 1975.

There was considerable interest in the possibilities of the technique in the device field (microwave and opto-electronic) and Bruce Joyce and Tom Foxon were invited to present a paper on the subject at the European Solid State Device Research Conference (ESSDERC) held in Munich in 1976. This rounded off the initial phase of MBE work at MRL rather nicely; the programme, however, prospered greatly and we will return to it in the next chapters.

**Power Devices.**

In the previous chapter we noted that following the withdrawal of GEC from ASM in 1968 the Stockport factory no longer had access to the GEC Wembley Laboratories for research support. Rapid action was taken to remedy this in the microwave device area by expanding the microwave device and circuit work in Salfords but in the somewhat larger field of power devices there was no immediate pressure for research support. It is probably true that the power device side of Stockport hadn't received much support from GEC, Wembley either so they didn't feel the lack in the same way as had the microwave people. That is not to say that they didn't have a need for research, however, and in 1972 following the appointment of Dr. GK Eaton (formerly of MRL and Southampton – see Ch2) as Plant Director in Stockport they approached MRL with a request that we should explore the possibilities for research support in power devices. To some extent Geoff Eaton was pushing an open door because we were aware of the lack of power device research and Jan Huart of Elcoma had also highlighted the matter. Accordingly, David Paxman, who had already had dealings with the microwave side of Stockport (and demonstrated notable ambassadorial skills), was given the task of formulating a research programme in the area.

This was a tough assignment as there was no MRL experience in power devices and the processes used in the factory development, whilst tried and tested in some respects, were largely empirical but arcane and closely guarded. To make any progress it was necessary to understand the essentials of the devices, the basic limiting factors in design and to deliver some applicable results in the short term to establish factory confidence in the Laboratory's capabilities. In the longer term there was a need to establish the scientific credibility of MRL in the field in order to gain entry to the wider power device community, whilst the ultimate goal was the invention of new technologies and devices leading to new products and markets.

*Mr. David Paxman*

The power devices of interest, thyristors, triacs, p-i-n diodes etc, were all, essentially, silicon p-i-n structures and the main difficulties facing their designers lay in the control of three basic characteristics. These were:- the breakdown voltage (determining the high voltage off condition), the electron-hole plasma density within the device (determining the on-state resistance) and speed with which the plasma could be extinguished (the switching time). The early work at MRL was concerned with shedding light on these matters and included the use of analytical techniques such as Secondary Ion Mass Spectrometry (SIMS) and Scanning Electron Microscopy (SEM) which were not available in Stockport. In the expert hands of Mike Burgess, using the voltage contrast mode, the latter proved to be particularly powerful. An invaluable technique for measuring carrier lifetimes and diffusion lengths in device structures using the SEM was also developed by David Paxman and Mike Burgess in co-operation with Dr. Roger Booker of the University of Oxford. The underlying theory of this technique was elegantly worked out by Fenia Berz and an exchange visitor to MRL, Dr. HK Kuiken. Carrier densities, both static and dynamic, were measured by Roger Cooper using an infra-red absorption method and here too Fenia Berz, this time together with Stella Fagg, established the necessary theory, in particular analytical solutions of the transport equations. This work was very productive and led to new methods of designing devices. Deep Level Transient Spectroscopy (DLTS), a method of characterising recombination centres, was developed in MRL by Stan Brotherton and Bertus Pals, during the latter's exchange visit to us in 1973, and this technique too was deployed to determine the nature of process induced defect centres in actual device structures.

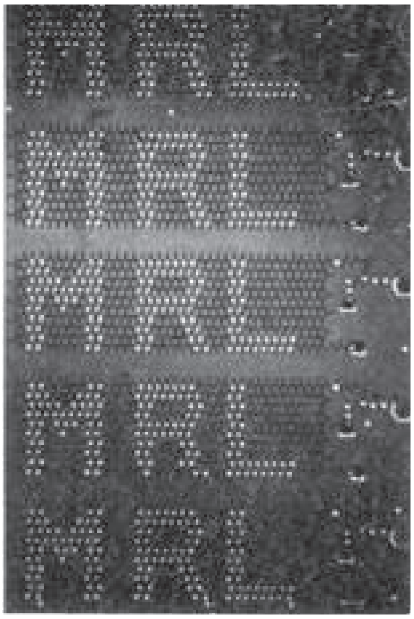
Work in these areas occupied the initial years of the power device programme at MRL. The results of the work and the resources of the Laboratory made a great impact in Stockport amply meeting the aim of establishing the confidence of the factory through the

supply of applicable data. Furthermore the quality of the work was such that it did much to establish MRL in the world power device community. An excellent foundation had been laid for the continued pursuit and expansion of the work, which we will discuss in the following chapters.

**Magneto-Optics and Electro-Optics.**

In this period work in Ron Pearson's Group was strongly focussed on magneto-optic and electro-optic phenomena and with their possible applications. The principal motivation for this work, apart from its intrinsic scientific interest, derived from the world wide interest in optical communications and the possibility of optically coupled computers. This stimulated a search for optically addressed storage and display systems.

The Group had been considerably strengthened in the late sixties and early seventies by the recruitment of Tom Keve, George Scott, Hugh Ralph and David Lacklison. Tom Keve had joined us from Bell Labs (I think that he was the only person we ever recruited from there), he was very able and astute, George Scott was an experienced spectroscopist, Hugh Ralph an outstanding theoretician and David Lacklison a most able experimentalist. Tom Keve later left MRL to pursue a commercial career in Elcoma, Eindhoven and George Scott joined BP Research in Sunbury.



*Magneto optic bubble display*

The earlier work on Yttrium Iron Garnet, which exhibits high Faraday rotation in the near infra-red was extended to materials in which the Yttrium is partially substituted by Bismuth. This was found to increase both the transparency and the Faraday rotation of the material in the visible part of the spectrum. Furthermore thin films of bismuth substituted garnets were found to support stable cylindrical magnetic domains, about 10$\mu$m in diameter (magnetic bubbles), within which the direction of magnetisation is opposite to that in the surrounding material. Polarised light passing through the garnet film then experiences different degrees of rotation within and outside the bubbles, which thus become visible when viewed through an analyser. The bubbles, stabilised by a static bias field perpendicular to the film, can be moved around by a rotating in-plane field and appear as mobile light spots. A serial access, compact display having a non-volatile memory was made, demonstrating the possibilities of the system.

Small displays using a transparent electro-optic ceramic, lanthanum doped lead zirconate titanate (PLZT)and exploiting the large quadratic transverse electro-optic effect in this material were also made in the Group. Also, together with CPA a stereo television system was realised employing goggles incorporating PLZT electro-optic switches. This was an ingenious scheme, devised by Tom Keve, Roger Cooper and Ian Fagg which actually worked very well.

The use of the ferro-electric Bismuth Titanate as an optical storage material was also explored by Alan Fox and Dennis Fletcher using crystals prepared by Tim Bruton.

All this work was of outstanding quality, based on meticulous material preparation and characterisation, however all the display possibilities arising from it were based on polarisation phenomena and were totally superseded by the later liquid crystal displays. The activity, nevertheless, forms an important part of the history of the Laboratory.

**Ion Implantation.**

Ion Implantation continued to be widely used in the various semiconductor projects undertaken in the Laboratory. The capability of the Danfysik implanter was systematically improved by Gordon McGinty and his colleagues in VPD. A new 200keV machine designed and built in MRL was installed in 1973, the mechanical design for this being carried out by Colin Overall and Les Francis.

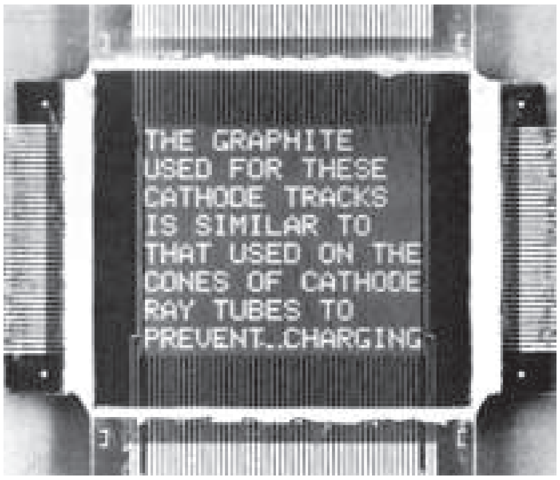
Work on the exploitation and understanding of the physics of the implantation process was pursued in the course of device work. A particularly interesting and valuable contributions was that made by Peter Blood in co-operation with Dr. Geoff Dearnaley, whilst on secondment to AERE Harwell, which elucidated the importance of ion channelling in determining the profile of implanted species. John Shannon also developed a most valuable technique for the control of the height of Schottky barriers using implanted surface layers.

*Dr. Peter Blood*

**THE VACUUM PHYSICS DIVISION**

**Matrix Display Tubes.**

A substantial amount of work on these devices continued in VPD during the Hoselitz era despite the pressures of competing technologies. A notable advance in the design was made by Jim Smith with the introduction of graphite cathodes rather than the earlier metallic electrodes. The use of graphite obviated the need for the inclusion of a high value



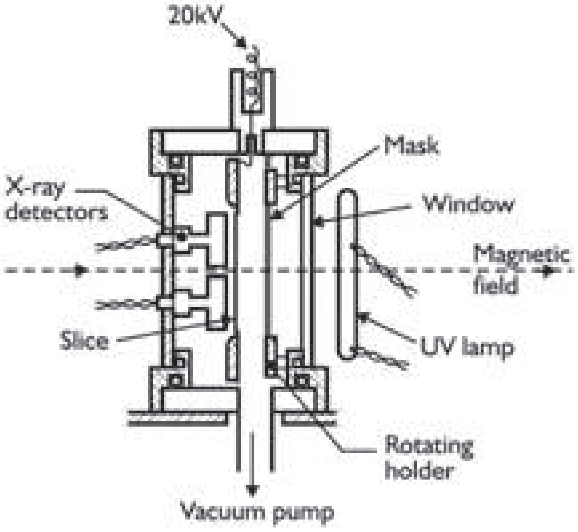

*Character panel*

resistor in series with each cell to provide internal storage. It also resulted in considerable simplification in processing of the arrays and in lifetime improvements. Arrays of 8 rows of 16 characters each comprising a 7x5 array of cells were made and operated being driven and addressed by means of circuits designed in CPA by Keith Johnson and John Singleton. The illustration shows an operating array.

**Electron Lithography.**

Work on the computer controlled electron beam pattern generator was continued during this time under the aegis of Nick King and Jim Beasley and was largely directed at enhancing the resolution limit, increasing the speed of pattern generation and the overall size of the generated pattern.

In addition another strand of the programme developed and this was the Electron Image Projector. The basic concept of the EIP is very straightforward, being simply to use electrons rather than light to reproduce an image of a master mask onto the surface of a silicon slice as sketched. The pattern to be transferred to the silicon slice is put down in gold or chromium, using the EBPG, on a quartz substrate this is then coated with a photo-emitter and illuminated with UV light from behind so that electrons are emitted from the open areas but not from those which are opaque. The emitted electrons are accelerated by a high electric field (c 1kV/cm) and brought to a focus by an axial magnetic field of about 3,000 oe. The axial field is provided by Helmholtz coils and is uniform over the slice area.




*Sketch of EIP*

*An Electron Image Projector*

The separation of the mask and silicon slice is 1cm. After many experiments the photocathode material chosen was caesium iodide which, whilst reasonably robust with regard to exposure to air and organic contaminants (emanating from the exposed electron resist), can readily be renewed when necessary. The mask life is very long as the mask does not come into contact with the slice. The method for alignment of successive masks which was eventually adopted was that of detecting the X-rays generated when the energetic electrons strike a tantalum marker pattern on the slice, there being a similar pattern on the mask. Despite initial difficulties it proved possible to make the alignment completely automatic. The alignment is actually achieved by making small adjustments to the focussing field using two additional orthogonal pairs of coils which are prominent in the figure. Results with the first Image Projector were extremely encouraging and led us to the view that this combination of the EBPG and the EIP could well prove to be the way ahead for integrated circuit fabrication. With this in mind we embarked on a programme in the Integrated Circuit and Techniques Group of SSP to demonstrate the viability of a technology based wholly on electron lithography. The second image projector constructed for this purpose is illustrated.

Julian Scott was primarily responsible for the initiation of the EIP project and was ably supported by other members of the group and Ian Lewin of the Engineering Division.

Alongside the work on machines an ex-CML chemist, Ted Roberts, was busily engaged on the problems of electron resists. Although working alone, quite independently of the established chemists (in the old VPL style one might say), he was brilliantly successful. He was much in demand as an invited speaker at specialist conferences, particularly in the USA and there is no doubt that his work contributed greatly to the technical success of the MRL Electron Lithography programme.

**Channel Multipliers.**

Work on the channel multipliers continued with considerable attention being devoted to the development of the technology of making large arrays of multipliers – channel plates. The channel plate image intensifier was further developed and an exploration of the possibility of making an entirely novel colour TV tube using a channel plate was initiated. This latter was to become known as the Falcon Tube and was intensively pursued in the next phase of the life of the Laboratory.

**THE ENGINEERING DIVISION**

**Replica Optics.**

Although the primary raison d'être of the Engineering Division was to support the work of the four scientific divisions, from time to time the discharge of this function resulted in the development of specialist activities which stood in their own right. One such was Harry Howden's development of the technology of replica optics. An example of this is to be found in the need for aspheric Schmidt correction lenses, required in projection TV systems, where traditional hand working is prohibitively expensive and totally unsuitable for bulk manufacture. Howden solved the problem by making a single glass negative by hand working and casting accurate replicas in a transparent plastic resin, of appropriate refractive index. The replicas were in a relatively thin layer of resin bonded to a flat glass substrate. The technique found a wide range of applications not only within MRL but also throughout the Concern.

*Mr. Harry Howden*

**Polar Light Distribution Photometer.**

In 1973 a light distribution photometer was designed and built in the Division to the specification of Philips Electrical Ltd and duly installed in their Photometric Laboratory in Croydon. The machine was automatic in operation and was able to accommodate luminaires having a light source diameter of up to 1.9m. It proved entirely satisfactory in operation and greatly enhanced the efficiency of photometric measurements in the factory. It was a difficult job well done by Ian Lewin, Brian Evans and Ray Headon

**Stored Energy Transmission Systems.**

Towards the end of this period Julian Beale, probably the most able and inventive semiconductor device scientist and engineer within the Philips Concern at that time,

became extremely interested in the possibilities of electronic control of automotive transmission systems. In 1973 we had made a strategic decision to terminate automotive work in MRL and I took the view that whilst Beale's ideas were interesting they were not our business and that we should do our best to wean him off them. As a Scientific Adviser though, Beale whilst attached to the Solid State Division, reported not to me as Divisional Head but to the Director. To my dismay, Kurt Hoselitz decided that Beale should have the opportunity to develop his ideas which, admittedly, could result in some valid patents. Certainly this decision was to some degree defensible but as far as I was concerned it meant that, effectively, I lost my deputy and right-hand man. Staff members were assigned to the project from CPA and Engineering and Beale became wholly absorbed with it, indeed he became quite obsessive. It was worrying to those of us who were close to Julian but none of us foresaw the tragedy that was to unfold over the coming years.

## ALL CHANGE AGAIN

Kurt Hoselitz was a man of strong views and one of them, we discovered, was that he did not believe that anyone aged sixty or over should be engaged in directing the activities of young research scientists. This we learned in June 1975 when Dr. Eddie de Haan, then the Philips International Research Co-ordinator, made a public statement in the Laboratory to the effect that Kurt would retire on his sixtieth birthday in August 1976.

There was genuine sadness in the Laboratory that we were to lose the challenging input, generally stimulating and encouraging (but sometimes quite the reverse), that our brilliant if mercurial Director had made in his comparatively brief period of tenure. There was also a measure of unease about the succession.

It fell to Peter Trier as UK Group Director of Research and Development to choose and appoint the next Director after consulting the Nat Lab Management and, of course the Senior Managers in MRL. He considered the Deputy Director, Norman Goddard, to be the obvious internal choice but both he and Goddard were firmly in favour of an external appointment if a suitable person could be found. A very interesting name from the academic world was recommended: a prominent personality and most successful research leader from the University of London. The MRL Managers supported the suggestion and the person himself was seriously interested. The Eindhoven Research Management invited him to the Concern Centre for a lecture visit and at the same time conducted a discreet interview at which they concluded that, whilst he was an impressive individual of

unquestioned world stature, his motivation was not sufficiently commercially oriented. Accordingly, Norman Goddard, who had already spent thirty distinguished years in MRL, who was well known and well regarded in the Concern and undoubtedly considered a safe pair of hands, was appointed as the next Director of the Laboratory.

As Director-elect Norman Goddard was relieved of his Divisional responsibilities, the role of Systems Divisional Head being taken by Keith Fuller, who in turn was succeeded as Group Leader by Robert Alcock. Norman undertook an extensive tour of the UK Group plants to expand his knowledge of the Group's activities and of the people involved and to publicise the work of the Laboratory. He also attended, with conspicuous success, the Management course at the celebrated Harvard Business School. In the spring of 1976 Norman and I made a joint visit to the United States with the two-fold object of attending an IEEE Device Meeting in Washington and of assessing the reactions of some members of the integrated circuit community to the Electron Image Projector as a lithographic tool. We visited Bell Labs, Signetics, Texas Instruments and Intel, where we were courteously received by Gordon Moore himself. There was sufficient interest to convince us of the viability of our EIP programme despite the fact that we were virtually alone at that time. For the Director designate this was a valuable visit insofar as it broadened his contacts in an area vital to the future of Electronics world wide.

Norman Goddard was duly enthroned as Director in a well-orchestrated ceremony which took place on the evening of Friday 30th July 1976 and a new era for the Laboratory started on Monday 2nd August – his first day as Director.

As for Kurt Hoselitz, he did not retire completely having been appointed as a consultant to Philips Industries and in 1980 he actually became a consultant in magnetics to the Laboratory. He also took up an appointment as a Research Professor in the University of Sussex where he returned to "hands-on" experimental physics and, to his great delight and satisfaction gained an SERC grant for his research programme. In 1973 Kurt was awarded the Glazebrook Medal and Prize by the Institute of Physics in recognition of his achievements in the organisation and application of science. This award of the Institute's most prestigious prize to our Director gave us all great pleasure.

# CHAPTER SIX

# PRL - THE GODDARD ERA 1976 - 1984

## THE FOURTH LABORATORY DIRECTOR.

The time that Kurt Hoselitz had spent as Director of the Laboratory was comparatively short and it seemed that we had only just come to terms with his unique style when it was time to change again.

Norman Goddard was an able physicist and engineer and a very competent manager, sound, considered and careful in everything that he did. Kurt Hoselitz, whilst of exceptional all round ability and insight, tended as we have already seen, to be intuitive, quick and impulsive. These latter were not characteristics shared by Norman Goddard. In the new regime decisions took time but they were always closely argued and without exception well presented. Norman was unfailingly courteous and, whilst he probably often thought it, I don't think that he ever called anyone an idiot but found more subtle but equally effective ways of conveying his opinions. It was all very different; particularly at the managerial level, but also on the shop floor and in the laboratories where one could be pretty sure that the Director was no longer likely to appear unheralded and inquisitorial. This is not to say that Norman did not get around the Laboratory, he did and early on initiated the most laudable practice of arranging visits to each of the Groups in turn. These were not surprise visits but they were informal in that the Divisional Heads were expressly not invited and the Director thus had an opportunity of chatting directly with the laboratory and workshop staff. Initially he managed to fit in at least one visit per week but, as is the way with such less pressing commitments, they tended to slip somewhat in later years. It was a good way to proceed however and, I believe, valued by the staff.

*Mr. Norman Goddard*

**LABORATORY ORGANISATION: "PHILIPS RESEARCH LABORATORIES"**

The period of Norman's incumbency was one of many changes in the Laboratory organisation, one of the most significant being that the name of the Laboratory was changed from **"Mullard Research Laboratories"** to **"Philips Research Laboratories"** on 1st June 1977. Ironically on the following day there was a meeting at Salfords with Mr. Jack Akerman and other Mullard Board members; they were not hearing about the change for the first time, however, and generally accepted the arguments for it. These were, broadly, that the new name better reflected the role of the Laboratories in relation to the whole of the UK Group, not simply the Mullard Company, and that it made the Laboratories' identity as a part of the Philips international research organisation explicit. This latter greatly enhanced public recognition of the Laboratories both nationally and world-wide. This was very real for us as the scientific world knew and respected Philips Research but, in truth, were much less aware of Mullard; thus doors, closed to Mullard, were opened for Philips. Generally the change was welcomed in the Laboratory.

Other name changes were that on 1st July 1976 the name of the Vacuum Physics Division was changed to the Applied Physics Division (APD). Within the Division Nick King's group was renamed Electron Lithography, Alf Woodhead's Image Intensifiers became Image Tubes and a new group, Powder Semiconductors, was established under John Orton. At the end of 1977 the name of the Solid State Physics Division was changed to Solid State Electronics (SSE) and Ron Pearson's group was renamed Physics of Solids – for old times sake. Interestingly it was Ron who first suggested, in his characteristic emphatic style, that we should change the name of the Division and also that of his Group. In 1979 there were some Group name changes in CPA, Eric Snelling's Ferrite and Piezoelectrics becoming the much more prosaic Device and Circuit Techniques Group whilst Richard Jackson's Linear Circuits and Display party was restyled Video Systems.

There were several staff changes in this period; some of these were planned but others, very sadly, were forced upon us by circumstances outside our control.

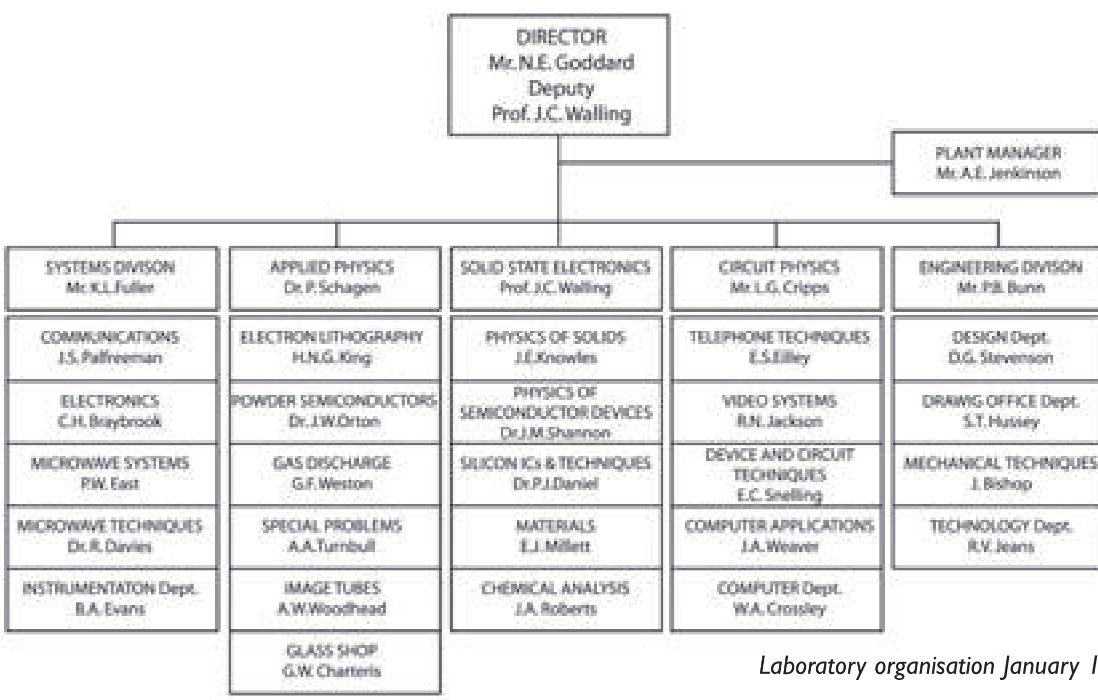
One such concerned Julian Beale who had continued, unremittingly, to pursue his ideas on automotive transmission systems. The Mullard Company had become interested and in consequence Beale became involved with them in trying to set up co-operative arrangements with automotive specialists including Ricardo Ltd. and motor manufacturers, in particular Ford of the USA, whilst continuing to develop his ideas. The whole thing became very taxing for Julian and sadly, in July 1977, he suffered a major mental breakdown

and was committed to hospital. At the height of his breakdown he had come into the Laboratory and the events of that day remain, for me (Acting Director as Norman was on holiday), an enduring and desperately painful memory. After some months Julian returned to PRL and undertook some experimental work on diodes with Roger Cooper, he was a shadow of his former self though and tragically in August 1978, whilst on holiday in Cornwall, he fell from a cliff during a solitary early morning walk and was killed. He was just 47 and a very great loss.

Ron Pearson, also, died suddenly on 31st December 1979 whilst visiting his family in Newcastle, he had suffered with respiratory problems all his life but had struggled determinedly against them. He was an outstanding scientist and a charismatic Group Leader and was just 50 years old when he died. His scientific achievements had been recognised in 1977 by the award of the Duddell Medal and Prize by the Institute of Physics, which had given him very great pleasure, in which we had all shared. A sad coincidence was that Mr. W Davis, a well regarded member of the Plant Department, also died suddenly a few days before Ron.

On a happier note Mike Malpass, our unfailingly cheerful, and most able, Personnel Manager, was promoted to Mullard Mitcham in August 1979. We were sorry to lose Mike but welcomed Richard Turner in his place.

Dr. Peter Daniel was appointed Deputy Divisional Head of SSE on 1st October 1978




*Laboratory organisation January 1980*

and on the same date I became Deputy Director of the Laboratory. The organisation of the Laboratory, at the beginning of 1980, was then as set out on the previous page. This was, in essence, the structure during the first four years of Norman Goddard's Directorship.

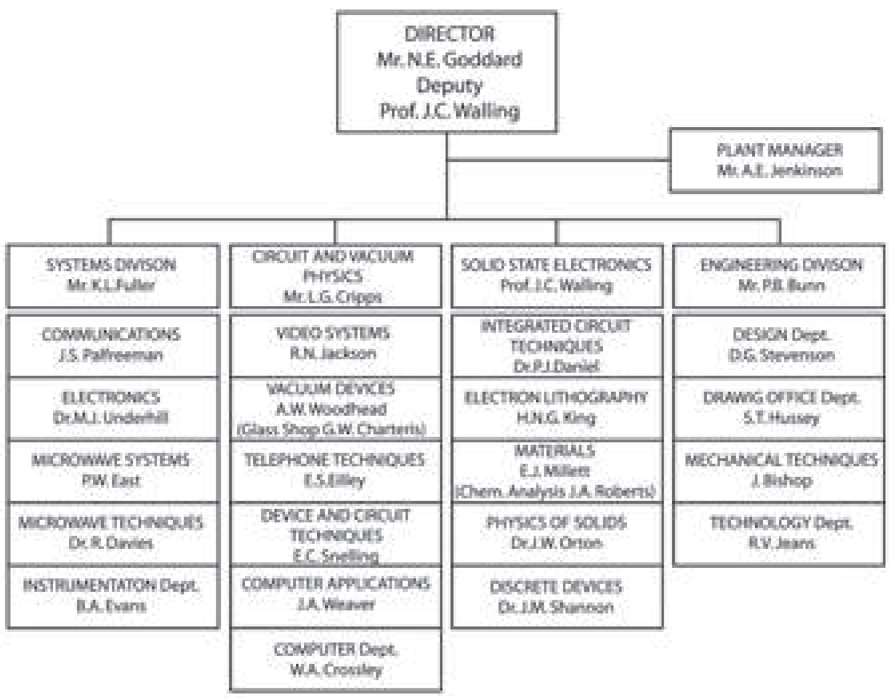
A major change in the structure, however, was effected at the end of 1980 following the retirement of Dr. Pieter Schagen OBE, Head of the Applied Physics Division, on 30th November after 36 years with Philips. We decided not to appoint a replacement for Pieter

*Applied Physics Division at the time of Pieter Schagen's retirement*

but to distribute the main APD activities between the other three divisions and to wind up the work on Gas Discharges and Powder Semiconductors. In consequence, Nick King and his Electron Lithography Group transferred to SSE, this was an area in which I was keenly interested and I was delighted (and rather honoured) to have the Group in my division. It also fitted very well with Peter Daniel's work on evaluating the EIP as a lithographic tool in integrated circuit fabrication. John Orton returned to SSE as Leader of the Physics of Solids Group, a major part of whose activity was becoming the physical characterisation of semiconductor structures grown by MBE. George Weston and Andrew Turnbull moved to Systems setting up an activity on Infra Red Techniques, which included the work on $CO_2$ lasers, and Alf Woodhead's Image Tubes Group, renamed Vacuum Devices, moved together with the Glass shop to Graham Cripps' division, renamed Circuit and Vacuum Physics. This was quite an upheaval, which, whilst largely devised by Graham Cripps and myself, was fully endorsed by Norman Goddard and the Concern Research Management. There was considerable and understandable disappointment amongst the APD Group Leaders that none of them was to become a Divisional Head, but the changes made very good sense with regard to the programme.

On 24th October 1980 Cliff Braybrook retired and was succeeded as leader of the Electronics Group by Mike Underhill. Brian Evans' Instrumentation team had separated from the Electronics Group some time before this. Cliff had been one of the founder members of the Laboratory (as we noted in Chapter 1) and over the 34 years since then had made a most notable contribution to the work and development of the Laboratory. Other changes in 1980 were that, in February, Robert Alcock was appointed Technical Adviser* to the Systems Division being succeeded as Group Leader by Peter East; Mr. Jim Wood, Plant Engineer, retired and was succeeded by Mr. Arthur Jackson, and the Director's Secretary, Mrs Norah Harris also retired.

Thus at the end of 1980 the Laboratory was organised in three scientific Divisions together with the Engineering Division as is set out below.




*Laboratory organisation December 1980*

Further changes, which took place during the remaining years of Norman Goddard's Directorship were almost entirely in the Systems Division and were the following:- In 1982 Mike Underhill was appointed Divisional Head in succession to Keith Fuller who had left to join Racal in November 1981 and Rodney Gibson replaced Mike Underhill as Group Leader of Radio Systems (a new name for the Electronics Group). John Palfreeman's Group was restyled Signal Processing at the same time and later that year, following the departure of

* *We had not had a Technical Adviser before and I have to admit to being unclear about the nature of the role.*

Peter East to Racal and that of Bob Davies to MEL, the two Microwave Groups were combined under Richard Vincent, regarded as a rising star.

Notable retirements during this period were those of Ron Charteris, Head of the Glass Shop, in 1981, Don Stevenson, Head of the Design Department, in 1983 and Stan Hussey, Head of the Drawing Office, in 1984. Each had many years of service to the Laboratory and had contributed greatly to its development. We were shocked by the sudden death, in 1982, of Maurice Kite, Senior Supervisor of the Mechanical Techniques Department, whom I remember personally with profound admiration and gratitude for his sterling work on the Goonhilly masers twenty years earlier. We were equally saddened in that same year by the sudden deaths of Mr. P Reason of the Stores and of Mr. Ken Turrell of the Plant Department.

There were some important changes in the UK Philips Group which affected PRL. The most important of these were the retirement on 30th June 1981 of Dr. Peter Trier as Group Director of Research and Development, Philips Industries, and, in 1979, that of Mr. Jack Akerman as Managing Director of the Mullard Company. Mr. Ivor Cohen (later to become Sir Ivor) was appointed as successor to Jack, and Peter was followed by Mr. Wim de Kleuver. Peter's retirement was a major milestone for the Laboratory.

## EXTERNAL CONSULTANTS

During this period the Laboratory employed a significant number of external consultants. These included Professor Roger Elliott FRS, Wykeham Professor of Theoretical Physics in the University of Oxford who was a great help to us over many years with problems in solid state theory, Professor Martin Redwood of QMC who helped with the acoustic surface wave work, Professor Ted Davies of Leicester, an amorphous silicon specialist and Dr. John Forrest of UCL an expert in phased arrays. There were also one or two former members of staff, Kurt Hoselitz, who was appointed to advise on magnetics problems following Ron Pearson's death, Colin Aitchison and Fenia Berz. Fenia was rather a special case as her appointment was almost full–time. She had been most unhappy about having to retire when she was 60 in 1976 and we most certainly had a continued need for her particular skills, so with the aid of John Bunton, the Mullard Company Secretary, we set up a Consultancy for her. It worked very well with an almost seamless transition from full time employment to part time consultancy and continued for several years to our mutual advantage.

University interactions were also evident in the other direction insofar as several of us held visiting appointments in UK Universities. In 1983, for example, Peter Blood was a Visiting Research Fellow in Sussex, Bruce Joyce a Visiting Reader in Sussex and Visiting Professor in ICST, John Shannon a Visiting Reader in Surrey and Mike Underhill and I were Visiting Professors in Surrey. These appointments were important to us in that they enabled us to access University expertise, to influence and enhance the nature and course of research work undertaken in the Universities and to increase awareness of Philips and Philips Research amongst the graduates and undergraduates – potential employees. They provide an indication of the growing stature of the Laboratory in the UK Scientific community at the time.

## JOB EVALUATION

At the beginning of this era the UK Philips organisation embraced the concept of Job Evaluation as a means of effecting a comparison of the value of jobs in a range of disciplines undertaken throughout the Group and hence a consistent salary structure. The scheme favoured was the Hay/MSL procedure and each establishment in the Group was charged with setting up a Job Evaluation Committee, having Management, Union and Staff representatives to evaluate the jobs in the establishment. There were also inter-establishment committees to seek parity of treatment across the Group. This was quite an exercise and I, for my sins (which I concluded must have been many and varied), was appointed chairman of the PRL Evaluation Committee. Jobs were evaluated in terms of three parameters, Knowledge, Problem Solving and Accountability. The specialist knowledge and experience required to do the job was quantified on the basis of a carefully prepared job description, and so too were the problems arising in connection with applying that know-how to achieve a result. In the Hay scheme, as I recall it, the Problem Solving score was a multiplier and therefore somewhat sensitive. Accountability was measured essentially in terms of the individual's budget. It was actually rather a good scheme and we became quite adept at evaluation. We adopted generic job descriptions and evaluations, that is to say that a senior scientist/engineer, for example, had the same evaluation throughout the lab, this greatly simplified what would otherwise have been an impossible task. Happily the scheme and our evaluations were eventually accepted without too much protest. Our greatest difficulty was with managers who some times over-estimated the value of the jobs done by their subordinates. In time, mid point salaries were established, Group-wide, by

means of a simple formula S = AH+B (H =Hay Score), naturally there was a performance related distribution about the mid point.

The Personnel Department, of course, was crucial in all this. Mike Malpass had a major part in the work of preparing and agreeing the job descriptions and in the evaluation process. I was immensely grateful to him.

**A NEW BUILDING**

At the end of 1977 Budget Approval for the construction of a new building, G block, was obtained. This was a three-storey block extending E-W and connecting with the southern end of E block. The construction was largely of brick and seemed very substantial, the rather tacky blue glass panels, which characterised the other blocks on the South site, were, happily, not repeated and the new block was architecturally much more satisfactory than its predecessors. It was intended to accommodate the Applied Physics Division thus completing the long held intention of locating all the scientific divisions on the South site and devoting the North site to the Administration Department and the Engineering Division.


*View of G block July 1979*

Unfortunately the construction of G-block proceeded rather slowly and it did not become available for occupation until 1981 so, sadly, Pieter Schagen never occupied the rather splendid double aspect office he had earmarked for himself! I don't know who did – it was probably turned into a conference room.

**THE PROGRAMME**

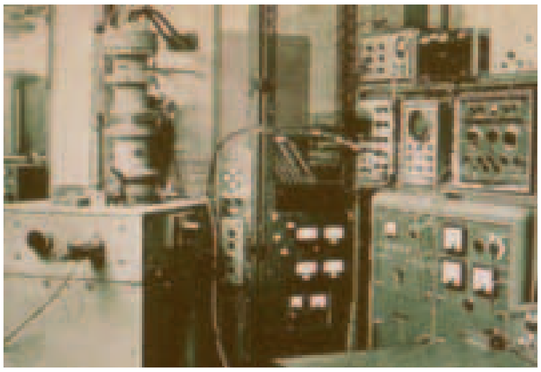
Notwithstanding all the organisational upheaval, which took place during this period, the work of the Laboratory continued to flourish and some of the most notable of its many achievements are outlined in the following paragraphs. For convenience they are presented under the post 1980 organisation.

## THE SOLID STATE ELECTRONICS DIVISION.

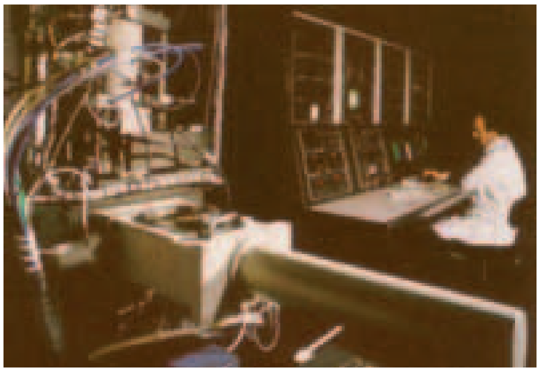
### Electron Lithography:

### a) The Electron Beam Pattern Generator.

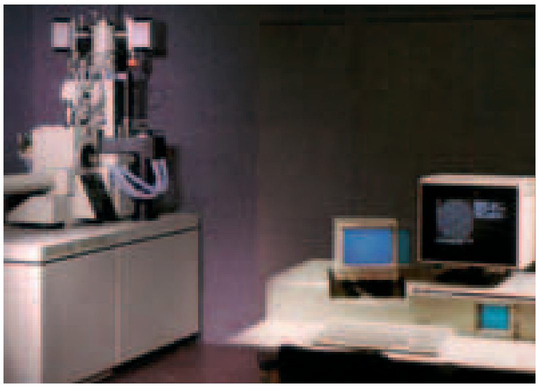
The prime rationale for the PRL work on computer controlled Electron Beam Pattern Generators evolved as the creation of a new product activity for Philips in the rapidly expanding and crucial area of integrated circuit fabrication. Accordingly, during the later years of the Hoselitz era and throughout that of this chapter there was close liaison between the Industrial Equipment (I&E) Product Division of Philips in Eindhoven in the development and manufacture of a series of these machines. The initial thinking of I&E was that the machines would be used solely for Philips' in-house IC manufacturing operations. It was soon realised, however, that the in-house market simply was not big enough and the very sensible decision was taken to offer the machines on the open market. To recapitulate, a series of machines for lithography had been made in PRL starting in 1966 with the EBM-2*, in which the MOST discussed in Chapter Four was made, EBM-3 was an enhanced version which came into operation in 1968 and during the early part of this current period EBM-4 was developed. The EBM-4 was the first machine capable of defining structures with sub-micron details; it incorporated a mechanical stage controlled by a laser interferometer and it was on this machine that the first I&E electron lithography system to be offered on the open market was based. Confusingly this was styled the EBPG-3; the first machines were delivered in 1979 and by 1985 the machine had gained a world wide reputation as probably the best sub half-micron machine then available.



*The EBM-1*



*The EBPG-3*



*The EBPG-4*

* *EBM-1 was designed for EB machining eg diamond drilling, not lithography.*

*Mr. Jim Beasley*

Further development in I&E, in close collaboration with Nick King, Jim Beasley and their colleagues in PRL, followed, resulting in the introduction of the EBPG-4. This superb machine represented the state of the art at the time and offered a sub 0.1μm resolution. The EBM-1, the very first PRL machine, the EBPG-3 and the EBPG-4 are illustrated on the previous page.

There was some concern about the effects of back scattered electrons in exposing resist beyond the area of the beam and thus reducing the definition and resolution. The effect, known as the proximity effect, was particularly marked in the case of a small geometry feature close to one of large area. Considerable time was spent by Hugh Ralph, and others, in devising a computer programme (a post processor) to correct for it. Trevor Neill together with Chris Bull undertook some painstaking experimental work which clearly demonstrated that the effect was greatly reduced when higher beam voltages (50kV+) were employed. High resolution machines such as the EBPG-5HR offered a 100kV option.

Work at PRL in this area was substantially reduced in 1985 but the I&E programme continued with the introduction in the early 1990s of the EBPG-5HR and EBPG-5HS machines which again represented the state of the art in this field. The 5HR (High Resolution) could provide a minimum feature size of 35nm, it was greatly sought after in the early days of Nanotechnology and in my post Philips days, as Co-ordinator of the SERC Low Dimensional Structures Programme, it gave me great satisfaction to endorse the proposed purchase of one of these machines by the University of Glasgow. The sum involved was well in excess of £1M.

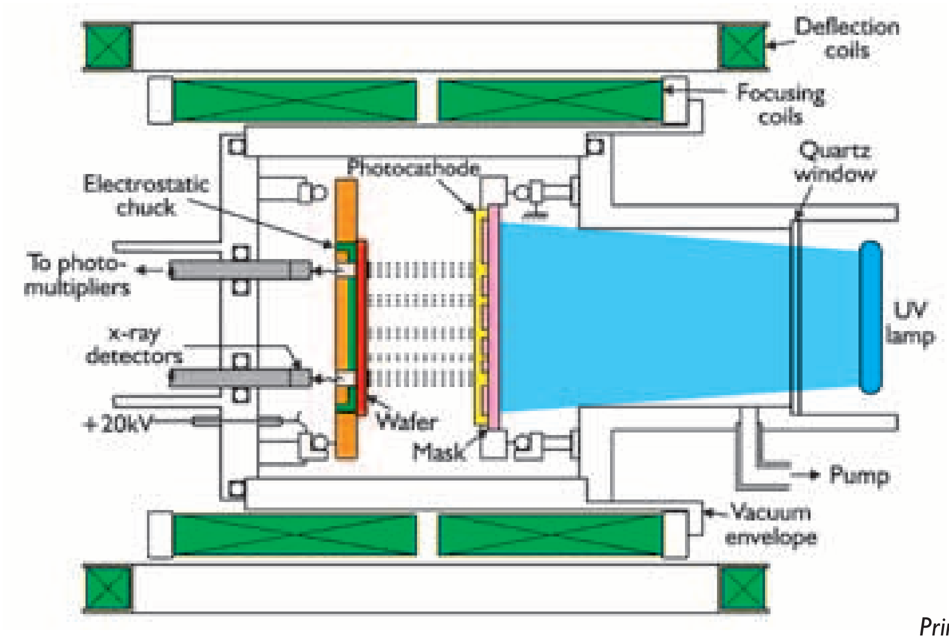
Our interaction with I&E involved much travelling to Eindhoven and we had a steady stream of I&E staff seconded to Salfords to work with Nick King and his colleagues. In the main it was a very agreeable and effective interaction. The I&E manager concerned, Ir Wim Troost, and his associates, Cees van Viegen, Rob van der Ven, Ron Beelaard, Rob Schmidt, Steve Wittekoek, Ron Melief and initially Karel van der Mast (who became Professor in Delft, but didn't lose touch) were all very competent and positive. There were difficulties occasionally of course but generally it worked well. There can be no doubt that the Electron Beam Pattern Generator programme was one of the major successes of the Laboratory both in terms of outstanding technical achievement and its transfer to the Product Group. Great credit is due to Nick King, who master minded the whole activity from the start, and to Jim Beasley (also involved from the beginning), John Kelly*, Tom Chisholm, Desmond

* *John Kelly made a significant contribution to the programme but left us fairly early on to head up a similar activity in the Hewlett Packard Laboratories in California.*

Squires, Tony Franklin, Alan Martin, Mike Plummer, Brian Herbert, John R Hughes and Mike Underhill (in the early days). The mechanical design was undertaken in the Engineering Division by Les Collins and Frank Witts and the PRL machines were constructed, with great skill by Brian Fairchild, John Taylor and Phil Cheal. The Divisional Heads concerned, David Allen, Pieter Schagen and latterly myself, were also very positive and closely involved with the work and its transfer to I&E.

**b) The Electron Image Projector.**

Work on the Electron Image Projector (EIP) continued for the whole of this period. Julian Scott, the original Project Leader, left the Laboratory in the 1970s to pursue a new career in medicine and was succeeded by Rodney Ward. Rodney brought great enthusiasm coupled with meticulous care to the project, which prospered greatly under his aegis. The rationale for the EIP was primarily that the continued trend to smaller dimensions of integrated circuit elements would eventually make their realisation by optical techniques impossible because of the wavelength limited performance of optical machines. Electron optical instruments do not share this limitation and we were convinced that the EIP offered a viable route to the realisation of circuits having sub-micron, indeed nanometric, geometries.




*Principles of the EIP*

In addition to its resolution capabilities the EIP offered other cogent advantages. It was a whole slice machine, that is to say the whole of the workpiece (a silicon slice) was exposed in a single shot in contrast to the step and repeat optical machines in which small areas are exposed sequentially. This parallel exposure capability ensured high throughput. The alignment of the projected images was fast, accurate and completely automatic. The registration of a pattern with a previously defined image is at least as important as the minimum achievable linewidth and the fast and accurate alignment capability of the EIP was an important feature. The alignment markers could also be used to monitor changes in slice dimensions due to temperature variations or process induced distortion, such changes could be compensated automatically by small adjustments to the main focussing field.

Several machines were constructed, the earlier ones could accommodate two inch diameter slices and subsequent bigger models could handle four inch diameter slices. The sketch on the previous page reminds us the essential principles of the EIP (which we discussed in Chapter Five) and this photograph is of a four inch machine with Rodney Ward.

*The 4 inch EIP and Rodney Ward*

The EIP was seen as a machine to be used on-line in integrated circuit manufacture. The demonstration of its capabilities in this capacity was therefore perceived as being most important and for some years work on the use of the EIP in IC fabrication was undertaken in Peter Daniel's Integrated Circuit Techniques Group in SSE. It was in this Group also that the painstaking work of evaluating the performance of the machine in a working environment was carried out. This included measurements over the whole slice area of linewidth, of alignment accuracy and the effects of slice distortion and bowing. These showed that the width of a 1μm line was maintained over a 4" slice with a standard deviation of 0.045μm and that the average alignment error in

x,y, rotation and magnification was only 0.037μm. A sample of 40 wafers was used in these experiments. Actual $I^2L$ and MOST circuits were successfully made and a very careful experiment undertaken by Keith Nicholas and Ivor Stemp showed that a yield of 98.5% of a simple device, incorporating 0.6μm lines and gaps, could be obtained. Some earlier experiments, using a 2" machine, were undertaken in the Nat Lab by Raoul Kramer and Rodney Ward but these were less conclusive, a fact attributed by Rodney to the machine's having been dropped during unloading in Eindhoven with some rather subtle, but significant, consequent damage to the alignment system.

I&E were interested in the machine and so too were ASM Lithography, a new specialist company, set up to make Lithographic equipment in which Philips had a substantial interest. ASM's main product line was (and still is) an optical stepper based on the Nat Lab's Silicon Repeater for which the EIP would be a direct competitor. The equipment manufacturers though were considered unlikely to be willing to take on the EIP without there being some instances of its being successfully employed in a Philips IC fabrication facility. This was a reasonable viewpoint and we had discussions with Elcoma with a view to persuading them to embark on some pilot experiments in one of the IC development units. They were reluctant; the use of the EIP involved process changes (different resists) and a new technique - it was just like the ion implantation story all over again. We did however get as far as having a meeting with Dr. Cees Kreigsman, who at that time headed up the Philips IC activity,* and Dr. Wolf Edlinger, who for many years had been head of Development in Southampton, the I&E and ASM Lithography people were there as well. They were well informed and really interested in the EIP, Kreigsman in particular, and at one stage we thought we had persuaded them. Sadly, though, conservatism prevailed again and they decided not to take up the EIP. Nevertheless in the course of 1984/85 a fully engineered, user friendly, 4" machine was delivered to Mullard Southampton for trials. Budget constraints however conspired against the exercise and I don't believe that the machine was even unpacked. That, very sadly, was almost the end of the story. I tried to persuade the SERC (Science and Engineering Research Council) to use the machine in their IC fabrication facility in the Rutherford Laboratory but failed; they too wanted a standard, no risk, process. We effectively stopped work on the EIP during 1984; of those concerned Rodney Ward joined Mullard Southampton, Ian Lewin (Engineering Division) Tony Franklin and Mike Plummer reverted to the EBPG and the device people took up other activities in PRL

Amazingly, the optical stepper, now UV, remains the standard lithographic tool of the

* *Sadly, Cees Kreigsman died a couple of years or so later having suffered a heart attack whilst on a skiing weekend in California in the course of a visit to Signetics.*

IC industry, EBPGs being used as reticle generators, and the anticipated resolution crisis is yet to materialise. If and when it does though I firmly believe that the EIP, possibly in a stepping version, would deserve to be revisited. It is certainly a much more practical route to higher resolution than the X-ray systems, employing compact but fabulously expensive, synchrotron sources, which were constructed some years ago. It now seems however that the more immediate limit on IC dimensions will be set by considerations of oxide thickness in relation to the dielectric constant rather than lithography.

**Power Devices.**

During this period work on Power Devices continued in John Shannon's Physics of Semiconductor Devices Group, renamed Discrete Devices in the 1980 restructuring. David Paxman remained responsible for the work and his team was strengthened in 1976 by Carole Fisher and Ken Whight. In addition David Coe and Paul Gough were devoting some time to the development of computer modelling programmes for these devices which were capable of dealing with both static and dynamic carrier distributions (TRIPOS for the OFF state and HECTOR for the ON state).

*Dr. David Coe*

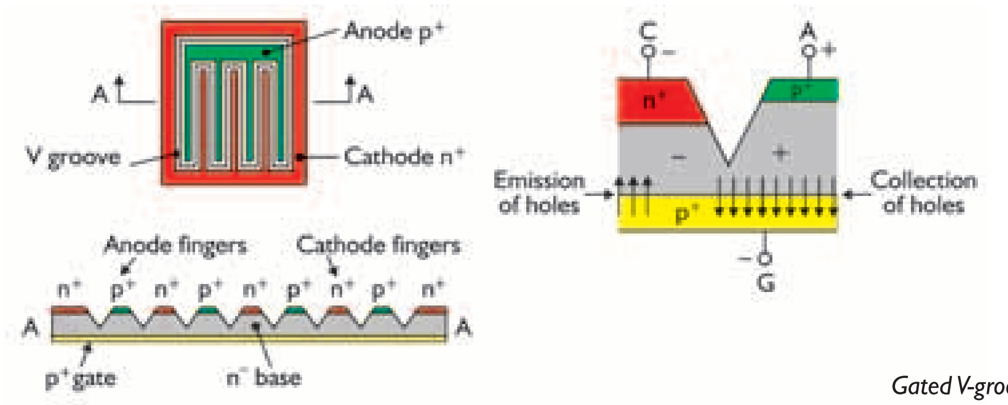
*Dr. Paul Gough*

Experimental work was undertaken on high voltage passivation schemes for the devices, which were potentially cheaper and more reliable than the traditionally used etched trough covered with a charged glass around the edge of the structures. The approach favoured was that known as Kao's rings in which a series of floating rings concentric with the junction to be passivated are diffused simultaneously with the main junction. The rings are covered with oxide. The work enhanced understanding of the functioning of such structures and put the design on a sound basis.

The theme of this phase of the work was largely to improve the understanding of existing devices and their design by the provision of computer based design tools validated by experiment and based on measurements of the necessary parameters. The work was generally rather successful and was well received in the factories who, as a result of the work were able to able to design their devices by applying the PRL computer programmes and new passivation schemes, such as the ring structures we have described. New techniques such as Neutron Transmutation Doping (NTD) were evaluated in PRL and introduced to the factories – not only Hazel Grove but also Nijmegen, Stadtskanaal and RTC Caen.

The first attempt at a new device was a novel type of gated V-groove p-i-n diode which

was designed by John Slatter and made by Carole Fisher. It was a fast power switch with a performance similar to that of gridded devices such as the static induction thyristor but which could readily be made with available technology. The construction of the device can be seen from the illustration below.




*Gated V-groove P-I-N diode*

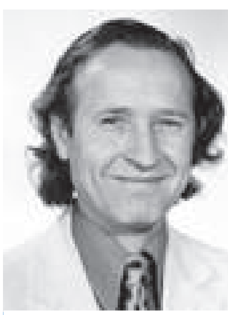
The whole power device field underwent something of revolution at the end of the '70s as a consequence of the introduction of the PowerMOS. These devices consisted essentially of parallel arrays of vertical current flow MOS devices and were capable of blocking 1000V or more and switching currents of tens of Amps. They required much lower input powers and were a great deal faster than their bipolar counterparts. A bewildering range of technologies emerged including V-groove and U-groove MOSFETS, vertical double diffused structures (HEXFETS) and double ion implanted structures (SIPMOS), Philips had a very useful variant on the SIPMOS process incorporating a tapered gate which offered important practical advantages. The PRL team were alive to the possibilities afforded by these new technologies and were able to apply their skills and experience in MOS devices and device modelling to devise a series of components which could be added to the SIPMOS power transistor without disrupting the basic process or compromising the device properties. These extra components were small MOS devices providing on chip logic and safety features. Towards the end of this period Ted Eilley began considering how the technology could be exploited. He came up with a device to be used in automobiles which became known as the Intelligent Power Switch, the IPS, and the process used later became known as PIPS-500 (Philips Integrated Power Switch 500A gate oxide).

This was a time of rapid change in the Power Device sphere and the Laboratory maintained close liaison with the factories, Hazel Grove in particular, providing assistance

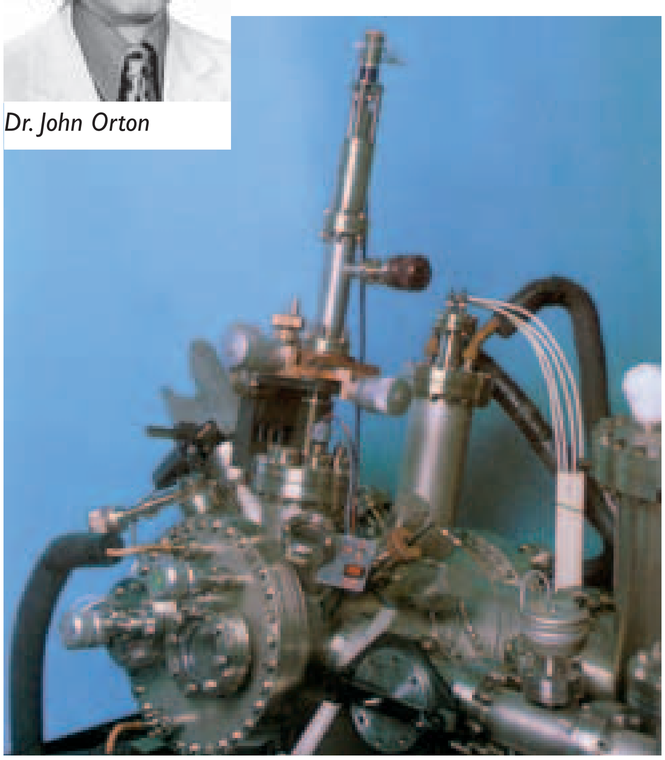
with the progressive establishment of new processes and device designs. This was very much appreciated and I well remember an occasion during a Research-Elcoma Discrete Devices meeting in Eindhoven when Alan Foster, then Development Manager of the Hazel Grove Power Device activity, asked to comment on the Research contribution prefaced his remarks by saying "Wonderful, wonderful PRL!" It was music in my ears and a great tribute to those directly concerned.

**Molecular Beam Epitaxy.**

The work on molecular beam epitaxy prospered greatly during the Goddard era. The team was increased in size; Colin Wood, who had made a notable success of the growth of InP by LPE, Jeff Harris, previously with Brian Ridley in Essex, Karl Woodbridge, a former member of APD and John Roberts, joined those concerned with the growth of layers in the Materials Group. The MBE grown structures possessed extremely interesting physical properties and, as the growth work progressed, the Physics of Solids Group became increasingly involved with measurements of their transport properties and optical characteristics. It too increased in size being joined early on by Geoff Duggan, a theoretical physics PhD from Leeds, Phil Dawson, one of Brian Cavenett's students from Hull and an outstanding experimentalist, and towards the end of this period by Peter Dobson, a former senior lecturer at ICST and Karen Moore, a sparkling new graduate from Nottingham.



*Dr. John Orton*



*PRL constructed MBE system circ. 1983*

In the first instance the work on MBE growth and the growth processes was undertaken in the Materials Group and the characterisation work in the Physics of Solids Group. The arrangement worked reasonably well but eventually it seemed more sensible to bring the whole programme together in one group and thus in 1983 the growth work moved into Physics of Solids, then led by John Orton.

The growth facilities developed as the programme grew. Initially the growth systems were largely made in-house in the Engineering Division by a team which included Bob Maddox, designer, and Rod Beck. These were sophisticated systems and performed very satisfactorily but in 1981 we supplemented them by the purchase of a commercial machine, the Varian 360 (aka GEN I). In 1984 following a recommendation by Piet Kramer's* MBE Management Committee (Andreas Miedema, Nat Lab, Laszlo Hollan, LEP, and John Walling, PRL) we bought a Varian Gen II – the ultimate system. The Gen II, which cost over £100,000, had a major impact on the work, but that belongs to the next chapter.

MBE GaAs layers grown for microwave device purposes in the late '70s included some

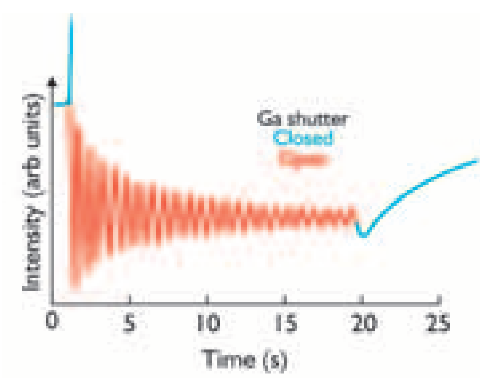
*Varian GEN II MBE growth system*

Sn doped layers 0.25μm thick on semi-insulating GaAs substrates which were supplied to SERL Baldock and also to LEP to be used in X-band MESFET devices for which they proved most satisfactory. It was soon discovered though that Sn was not a very satisfactory n-type dopant in MBE because of its tendency to segregate to the growth surface; better results were obtained using Ge or Si. Hyperabrupt varactor diodes made by Jeff Harris and John Woodcock using MBE grown Ge doped GaAs established new performance levels for an

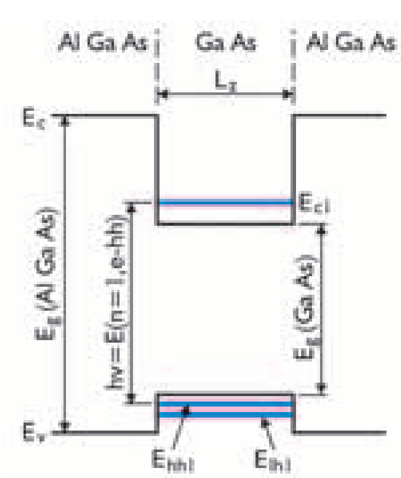
* *Dr. Pieter Kramer was International Research Co-ordinator at that time. He was very supportive of our MBE programme.*

X-band microstrip parametric amplifier. These and other results of a similar nature indicated that the MBE growth technique offered real advantages, in particular in respect of its ability to realise sharp, well controlled doping profiles and heterojunctions, and deserved further research. On the device front attention became focussed on opto-electronic devices but before we look at these we should note a fascinating development which permitted the MBE growers to count atomic layers literally one by one as they were deposited.

RHEED, Reflection High Energy Electron Diffraction, was used routinely in the growth systems to monitor the growing surface, the pattern being observed as a series of streaks and dots on a fluorescent screen. Bruce Joyce recalls that, one afternoon in 1981, a very excited Jeff Harris, then comparatively new to the team but a very able and experienced scientist, claimed that the pattern was varying in a periodic fashion as the film growth proceeded. The first response to Jeff's discovery was rather dismissive suggesting that it was all due to the trains on the South Coast main line, which runs within a hundred yards or so of the Laboratory. Jeff, in no way daunted, persisted in his claim insisting that his colleagues, including Bruce, should come and see for themselves. This they did and their scepticism turned to amazement as they realised that the period corresponded precisely to the deposition of a single molecular (Ga+As) layer. The phenomenon provided a very accurate means of measuring deposition rates in-situ during growth. The figure on the left is a plot of the intensity oscillations of the specular beam in the RHEED pattern from the surface of a growing GaAs layer, the period of the oscillations corresponds exactly to the growth of a single Ga+As layer.



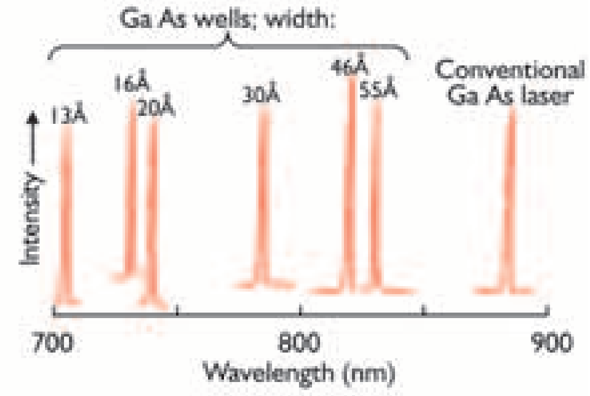

*RHEED oscillations in MBE growth of GaAs*




*A GaAs AlGaAs quantum well structure*

This serendipitous discovery provided a very powerful tool for the precise control, atomic layer by atomic layer, of MBE growth, which was fully exploited in the successful growth of Quantum Well structures. Such a structure is a semiconductor film, whose thickness is less than the de Broglie wavelength of electrons in the material (c 50nm for

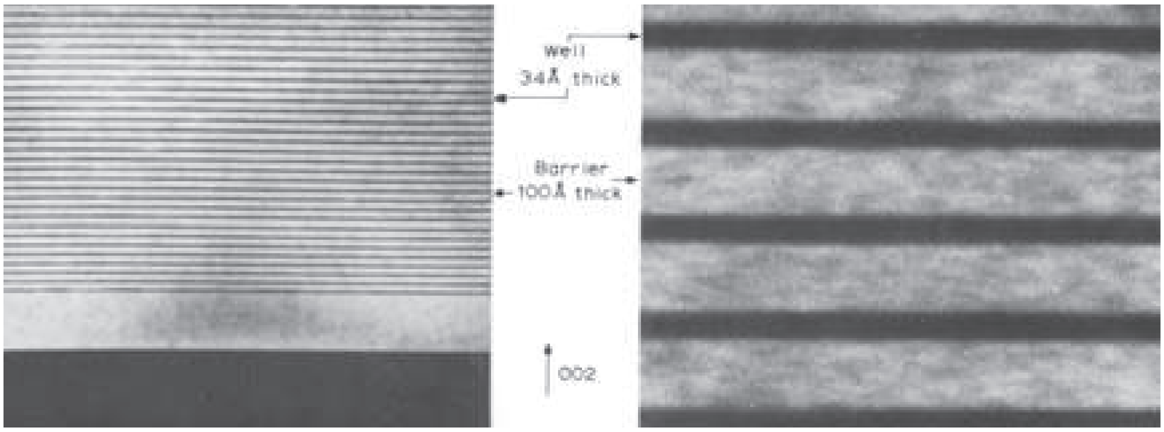
GaAs), contained between two layers of a wider band gap material. Carriers in the sandwiched layer see potential barriers at the interface and are confined in the direction normal to the layers. This confinement results in a set of new quantum states, each of which is the lowest in a series of energy bands. In essence in such a quantum well the bottom of the conduction band is shifted upwards and the top of the valence band moves downwards thus widening the effective energy gap. The energy level diagram for a quantum well structure formed by a layer of GaAs sandwiched between two layers of AlGaAs, a wide gap material which, fortuitously, is lattice matched to GaAs permitting the growth of strain free structures, is shown opposite.




*Emission spectra from GaAs/GaAlAs MQW lasers*

The control of the process was such that multiple quantum well structures with no variation in the number of layers in each well were grown. Injection laser devices were made from these layers and the emission spectra of a series of such lasers are shown. The device with the 13AU wells operated at a wavelength of 709nm which was the shortest wavelength achieved in such a device. Karl Woodbridge grew these structures and Peter Blood, Dennis Fletcher and Paul Hulyer made the lasers.

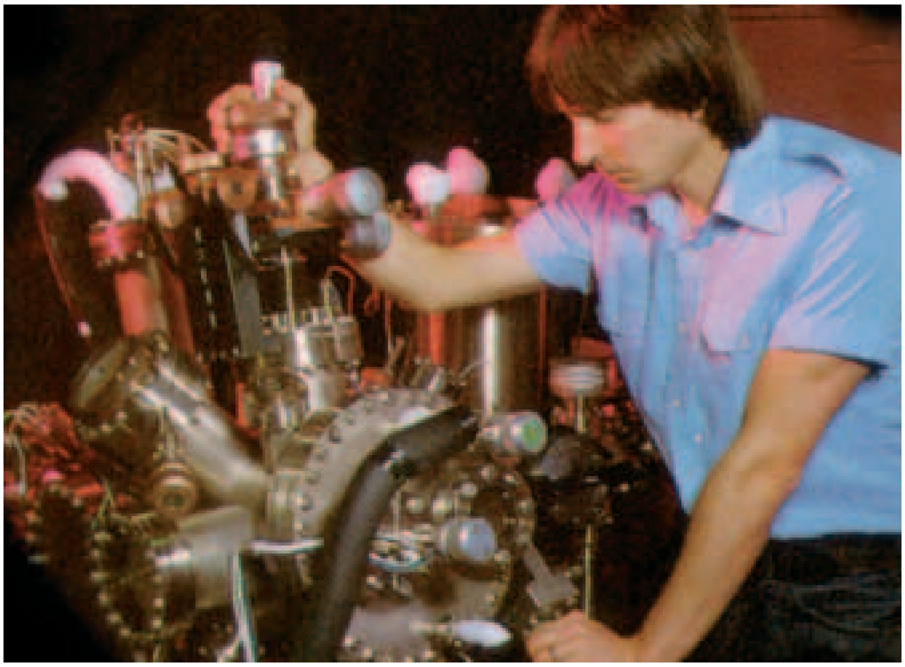
The work of Jon Gowers and Paul Fewster using transmission electron microscopy and X-Ray diffractometry respectively was most important to our understanding of these structures and some beautiful TEM micrographs of an MBE grown MQW structure are shown below.




*TEM micrographs of an MQW structure*

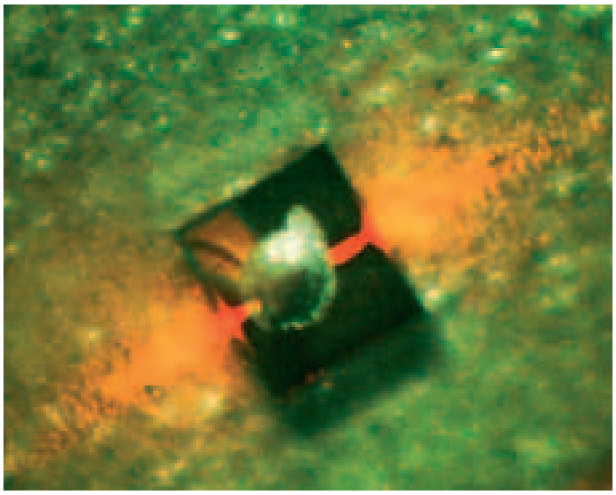
*Dr. Jeff Harris*

*Dr. Jon Gowers*



*Dr. Karl Woodbridge with growth system*

This exciting device directed work was supplemented by some most elegant basic work on the nature of the reconstructed GaAs surfaces by Bruce Joyce and Jim Neave. The basic techniques employed were those of angle and energy resolved photoemission from the surface. The incident energies required were between 20eV and 200eV and were available from the synchrotron at Orsay, Paris with whom Paul Larsen from the Nat Lab had an established co-operation. The Nat Lab had acquired a substantial amount of beam time



*Visible Laser emission from 13AU MQW structure*

*Dr. Jon Gowers and the TEM*

at Orsay in exchange for a monochromator, custom-built for the French in Eindhoven, and some of this time was made available, *gratis,* to Bruce and Jim as well as to Paul. An MBE system partly constructed in PRL was installed on one of the Orsay beam lines and, additionally, a very useful and confirmatory collaboration took place with theorists Dr. J Pollman and Dr. A Mazur of the University of Dortmund. Thus the work was successfully completed at rather little cost to us apart from Jim and Bruce's travel costs. Whilst some of us may have felt a little envious of the various extended visits to Paris required this was quite a difficult task as the work had to be done when the beam was available. This was very unpredictable and was often at short notice in the small hours, calling for considerable dedication on the part of our valiant researchers.

The scientific importance and quality of this work was recognised in 1981, to our great pleasure, by the award to Bruce Joyce of the Duddell Medal and Prize by the Institute of Physics.

**Monolithic Hot Electron Transistors.**

In 1979 John Shannon proposed a novel type of transistor, called the Hot Electron Transistor which used the transport of hot electrons to produce transistor action. In principle the device offered the possibility of a high frequency performance far superior to that of a bipolar device because, being unipolar, it could be driven at high current densities with negligible minority carrier charge storage and very high base doping levels could be used. The device consisted of a degenerate semiconductor base region bounded by two potential barriers, one for the emission and the other for the collection of hot electrons. The barriers were formed using narrow, highly doped acceptor regions the thickness and doping levels being such that they were substantially depleted of holes under all bias conditions. Structures were made using ion implantation, which supported the theoretical expectations but also evidenced practical difficulties with regard to the realisation of high efficiency emitters. This was, however, a completely novel and sound concept and as such forms a noteworthy part of the history of the Laboratory. The implantations were made using the Lintott Ion Implantion machine, which was purchased and installed during 1979. The work of fabricating the hot electron transistors, demanding in the extreme, was largely undertaken by Mrs Audrey Gill.

*Dr. John Shannon*

In recognition of his pioneering work on ion implantation John Shannon became, in 1983, the first recipient of the Institute of Physics' Paterson Medal and Prize.

**Small Particle Magnetism.**

Magnetic research was largely wound down during this time but it is worth noting that John Knowles undertook an experimental investigation of the properties of the individual magnetic particles used in recording tapes. This most painstaking work was very well received in the Product Division.

**Cadmium Mercury Telluride (CMT).**

Cadmium mercury telluride is a narrow gap semiconductor extensively used in infra red detectors and which had, for many years, been worked on in Mullard Southampton for that purpose. The Southampton work had been conducted in collaboration with RSRE Malvern but without any involvement of the Salfords Laboratory. During this period, though, this situation changed and in 1979/80 we mounted a programme of epitaxial growth and assessment of this difficult material. Both vapour phase and liquid phase techniques were employed with considerable success and detector arrays were made in Southampton using this material. Those principally concerned with the growth programme were Brian Easton, Peter Whiffen and John Brice whilst David Lacklison and Jim Hewett undertook the physical measurements on the layers.

## THE CIRCUIT AND VACUUM PHYSICS DIVISION

**Television.**

There were several strands to the television work undertaken in this Division during Norman Goddard's time as Director. These included pioneering work on the individual reception of satellite television signals, the development of flat CRTs (initially undertaken in APD), work on high definition TV systems, in co-operation with the Nat Lab, and, towards the end of this period work on Active Matrix Liquid Crystal Displays. As the bulk of this latter activity was undertaken from 1985 onwards we will defer it to the next chapter.

**Satellite Television.**

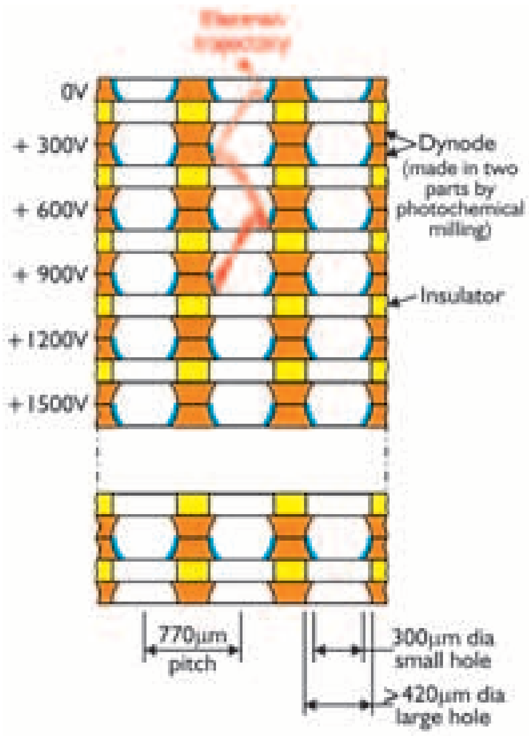
We noted earlier that in 1970 Ken Freeman and collaborators had undertaken a study of direct broadcast television from geo-stationary satellites concluding inter alia that the optimum frequency for such transmissions was 12GHz. This work was followed by the design of systems and microwave sub-assemblies for the individual reception of such signals. In January 1976 the Canadian Government launched the Canadian Communications

Technology Satellite in order to carry out various experiments, including some on broadcast television reception. Philips were invited to take part and MRL (as it was at that time) co-operated with Philips Video, Eindhoven in the design and construction of receivers for the experiments. One of these receivers was a wholly MRL design. This included a fixed-tuned frequency converter from 12GHz to 410MHz located at the focus of the receiving dish aerial and consisting of a microstrip Schottky barrier diode mixer followed by a 40dB amplifier; the local oscillator was a frequency stabilised Gunn device at 11.6GHz. Further conversion took place in an indoor unit and the system provided excellent picture and sound quality. This was one of the first successful experiments in direct broadcast Satellite TV; it was part of an extended series of experiments and some years later (1983) the IERE awarded Ken Freeman the P. Perring Thoms Premium for his outstanding paper on "Direct Broadcast Satellite Receivers".

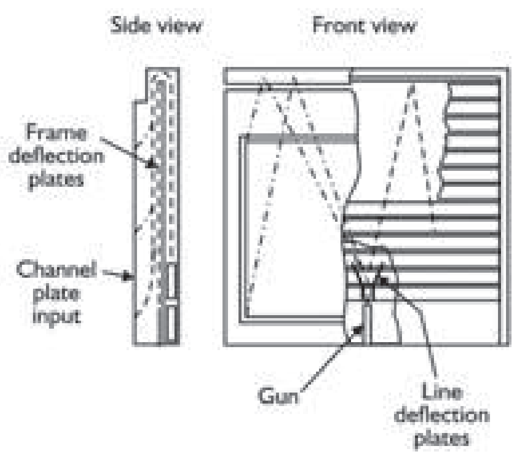
**Flat CRTs FALCON and MERLIN.**

In a conventional CRT the electron beam has to perform two functions, firstly it addresses the picture, and secondly it generates the light output by energising the phosphors. The latter function demands high energy and therefore dictates a high current, high voltage and therefore a stiff beam. The address function on the other hand would be more easily executed with a low voltage flexible beam but is possible with the high voltage beam. It is the need for a high voltage beam though which dictates the bulk and weight of the conventional tube.

Separating the two functions of the beam then was a desirable goal and the use of a channel multiplier plate offered the possibility of doing just that by using a low voltage low current beam to address image points on a large area channel plate and then accelerating the amplified electron stream to form the picture. The exploitation of this idea was the motivation of a major project, which started in APD at the beginning of this period and, following the 1980 restructuring, was carried on by the same team in the Circuit and Vacuum Physics Division.




*Metal dynode electron multiplier*



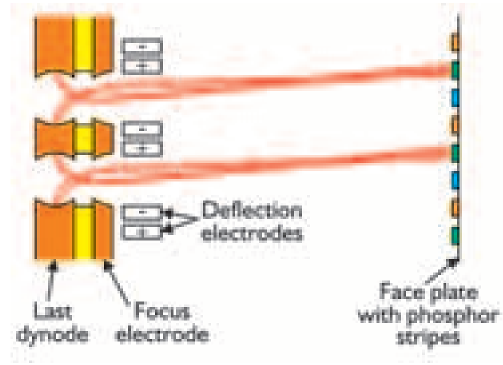

*Flat deflection system*

The channel multiplier plate, central to the concept, was formed by assembling a stack of metal dynode plates, made by standard shadow mask technology, and separated by glass beads as shown on the left.

In an actual tube the address function is executed as sketched below. A low voltage electron beam, initially screened from an array of frame deflection plates, is scanned horizontally (line deflection) and then turned through 180° and exposed to the frame deflection field by which it is deflected, as required, to the channel plate input. Within the channel plate the electron current is amplified and, emerging, accelerated to a sufficient energy for creation of the image on a phosphor screen. This electrostatic deflection system enabled the total thickness of the tube to be reduced to a few centimetres and allowed the use of a metal envelope and a flat face-plate. Colour selection was possible by using an electrode system at the multiplier output to focus the beams emerging from the channels onto the screen. Deflection electrodes moved the beam laterally to vertical phosphor stripes in the three primary colours separated by black guard bands as in the Trinitron and the erstwhile beam index tube. This system is illustrated opposite.

Two versions of this type of CRT were made. The smaller, the MERLIN tube, was aimed at datagraphic applications and employed a glass channel plate rather than the metal dynode structure. The larger, the FALCON tube, employing the dynode structure, was aimed at TV applications and picture sizes greater than 15" diagonal. Working samples of each were made (including colour tubes for Falcon), and, opposite, Daphne Lamport, one of the prime movers in this work, is portrayed testing a Falcon tube. A full colour version of Falcon was made and demonstrated in PRL during 1986/87.

The Merlin tube was transferred to development in Mitcham and pre-production samples supplied to customers, whilst Falcon was taken up by the CRT Development department in Eindhoven. Eventually work on both tubes was discontinued, that on Merlin because of the perception that the datagraphic market would be taken over by LCDs and that on Falcon because of concern that the costs would be too high for the TV market. In retrospect the Merlin decision was probably correct but the Falcon one looks more questionable when one considers the current prices charged for TV sets boasting large area flat displays. This was another very bold attempt to devise a viable and much less bulky alternative to the shadowmask tube. Falcon was technically very successful and that it was so is evidence of the ingenuity, skill and determination of those concerned who were, principally, Alf Woodhead, Daphne Lamport, Alan Knapp, Derek Washington, Roger Pook,




*Deflection method of colour selection*

*Miss Daphne Lamport and a Falcon tube*

Colin Overall, Harry Stone, John Mansell, Andrew Guest, Ron Gill and Les Francis. Ken Freeman and his colleagues were also involved in system studies and in developing circuits for driving the tubes and, of course, many of the basic ideas and the initial inspiration for the programme originated from the indefatigable Pieter Schagen. The team presented a group of papers on these tubes at the IEE in 1984 and, most gratifyingly, was awarded The Institution Premium for 1983/84 as a result.

**Matrix Display Tubes.**

The work on these devices continued in APD during the late 70s and culminated in the construction of a 4x80 character display for use in word processors. This display, complete with its rather sophisticated address circuitry, was transferred to development in Development in Heerlen in 1979. This marked the end of the Laboratory's work on Gas Discharges, which had formed an important part of the programme since the Vacuum Physics Laboratory moved to Salfords in 1948. Those primarily concerned with it over the years were George Weston himself, Brian Stocker, Ray Hall and Jim Smith in VPL/APD and Keith Johnson and John Singleton did the circuitry work in CPA.

**Hi-Fi Television.**

At this time there was a wide spread view in Philips that the viewing experience afforded by existing television receivers would, increasingly, be considered unsatisfactory and that attention should be given to the enhancement of its quality. Richard Jackson of PRL and Ir Leon Tan of the Nat Lab did a great deal of work on this. They recognised that a new Hi-Fi TV system would have to co-exist for some considerable time with the existing 625 line standard simply because of the huge investment in equipment and programme material. A first experiment was then to construct apparatus working on a provisional Hi-Fi standard of 1249 lines as this allowed a fairly straightforward conversion from the existing 625 line standard. The system was demonstrated in the Laboratory in 1982 using a 1249 line wide-screen projection display with more than 1 Megapixel. This was based on three 5" high resolution 50kV projection CRTs, developed in PRL and employing optical components, 180mm 9 element f/1.0 lenses, some of which were made by Harry Howden's replica techniques.

The improvement in picture quality was quite striking but the programme was rather overtaken by events. These included the proposal to introduce a UK direct broadcast

satellite (DBS) service employing the MAC (multiplexed analogue components) system that avoided many of the problems, such as the various cross effects, inherent in the existing systems, which the Hi-Fi programme had set out to alleviate if not eliminate. MAC also improved picture quality and resolution. The programme thereafter reduced and became a study of extended definition television based on the EBU MAC encoding system. It was nevertheless a valiant effort and an important part of the PRL history. Those involved included Richard Jackson, Ken Freeman, David Parker, Mike Hulyer and Harry Howden together with SL Tan and LF Mujica in the Nat Lab.

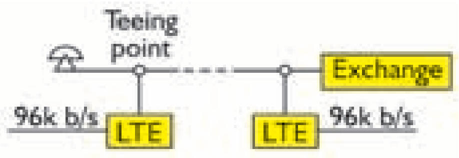
**Gyrators.**

We noted previously that the Gyrator offered a route to the realisation of integrated selectivity in TV. Work on the system went on during this period and a gyrator circuit known as FILT 2 was developed and transferred to Nijmegen during 1978/79 by Ken Moulding and his collaborators.

**Telephony.**

The work on the application of digital techniques in telephony, which had commenced in the previous era, continued but the emphasis shifted from main transmission systems to the subscriber end; the "last mile" between the local exchange to the subscriber had to be digital too.

British Telecom (BT), as the telecommunications part of the GPO had become, had a need for what was known as a pair gain system (1+1) for subscriber lines. This enabled two subscribers to use, completely independently, a single wire pair by providing an additional carrier, at a frequency above that of the audio band used by the first subscriber, onto which was modulated the information from the second service. This required additional electronic equipment at either end and whilst an analogue scheme existed it had proved unreliable; BT were keen to explore a digital alternative and to this end placed a studycontract with PRL.




*1+1 system configuration*

There were many aspects to this. In the first place twisted pair cables are not good transmission lines, irregularities, joints and discontinuities set up reflections which, in full duplex operation, may mask the incoming signal, it was thus necessary to find a means of

minimising this effect. For this purpose a sophisticated digital sub-system, described as an adaptive echo-canceller was devised. This operated by minimising the correlation between the corrected received signal and the local transmitter output and at a bit rate of 96kb/s achieved a 50dB suppression of the received echo.

Several trial LTE (line termination equipment) systems incorporating the results of this work were constructed and operated, together with BT, and were eventually manufactured and marketed by TMC. They made it possible to supply the subscriber with digital services using the same line as that carrying the analogue bi-directional voice channel. The analogue and digital services operated simultaneously. A small Private Automatic Branch Exchange (PABX) style system was constructed. This was known as PRIDE (an acronym – Philips Research Integrated Digital Exchange) but did not lead to a product activity.

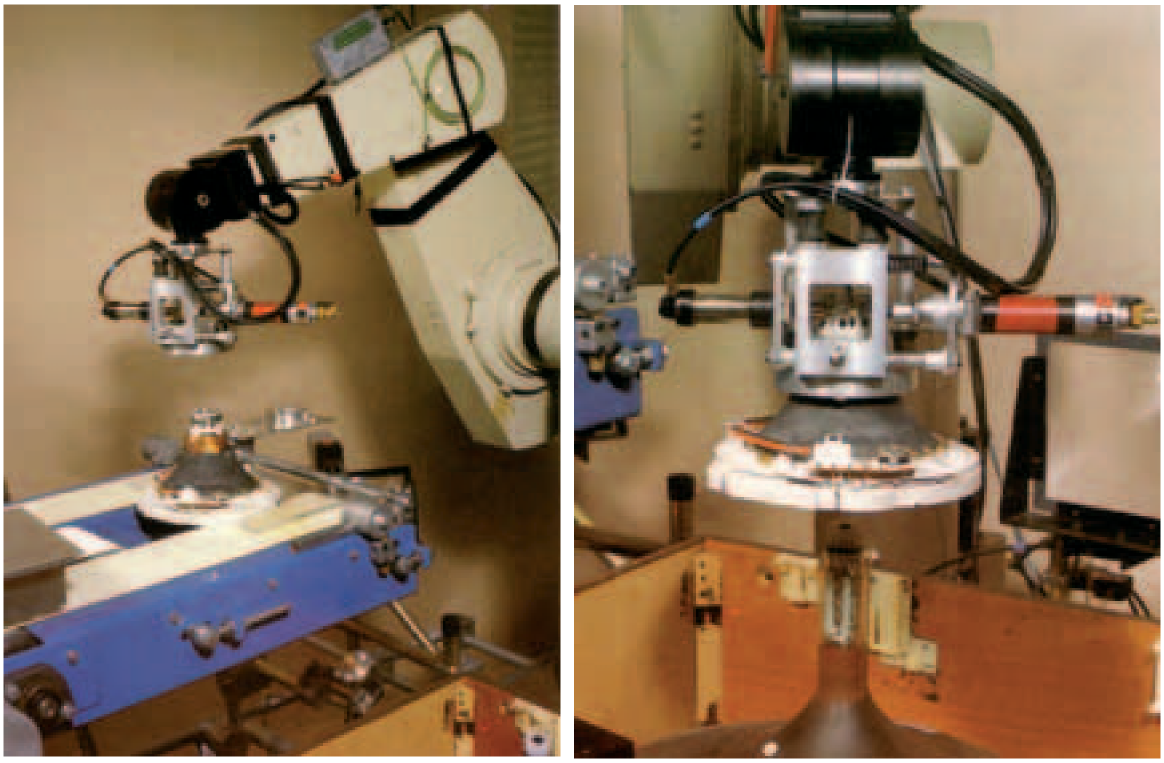
In 1984, or thereabouts, a Philips commercial policy decision resulted in the termination of research activities in guided wave telephony and this activity came to an end. Those concerned in PRL were Ted Eilley, John B Hughes, Mike Vry, Neill Bird and Randeep Soin.

**Optical Character Recognition.**

The work undertaken by Tony Weaver, Peter Saraga and their collaborators in the former OCR sphere evolved during this period towards the development of "pick and place" machines. These permitted the automatic assembly of such diverse entities as printed circuit boards at one extreme and the placement of the deflection unit on a television tube at the other. Several visually controlled robots together with a sophisticated operating system, ROBOS, were successfully developed for these purposes and were actively employed in the factories.Examples of machines for the automatic assembly of printed circuit boards and for the placement of the TV deflector unit are illustrated on the right..

**Computer Department.**

In 1979 the Laboratory's central computer system were greatly enhanced by the purchase and installation of a second ICL 1904S. At the same time substantial improvements were made to the GEORGE 3 operating system. Following the completion of G-Block the department was re-housed in the new building. Initially the GEORGE 3 system (very advanced in its day) was accessed by teletype printer terminals which were



*PUMA in action, about to pick up a TV Deflection Unit pictured above, placing onto neck, pictured right*

slow and very noisy. In 1981 GEORGE was replaced by a Gandalf PACX (Private Computer Exchange) allowing 256 terminals to access the machines – a sort of spaghetti junction.

Further big changes took place during 1983/84 when several VAX 11 computers were installed together with an IBM 4341 and the ICL machines were phased out. For the first time we were using systems similar to those in the other Philips Laboratories and became part of the Corporate Research computer network.

## THE SYSTEMS DIVISION

This was a time of change in the Systems Division, not only because of the 1981 restructuring, but also because the era of big radar systems projects, such as Porker, Abbey Hill and Madge, which, earlier had provided the main initial raison d'être for the Division, effectively came to an end.

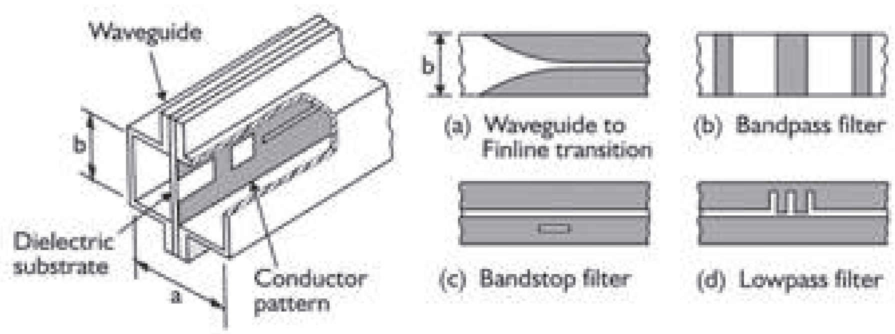
Early on in the period there were one or two exercises such as PAIR (Precision Approach Interferometer Radar) and MATILDE but that was virtually all. PAIR was interesting in that it made use of the SSR (Secondary Surveillance Radar) transponder

installed on all aircraft thus obviating the need for a high power ground based transmitter. The users however requested that the system should be backed up with an S-band primary radar which made it rather conventional. MATILDE was a low cost microwave analysis receiver for ships, enabling the identification of possible hostile radars. It operated in 7.5GHz – 18.0GHz band and measured pulse width, amplitude, bearing and carrier frequency using the Robinson IFM system - naturally! Richard Vincent was responsible for PAIR and Peter East, shortly thereafter to leave for RACAL, for MATILDE.

The Microwave work became directed to the development, in association with Mullard Hazel Grove (Stockport) and in some cases with SSE, of small microwave subsystems. A particularly fruitful technology for the realisation of such sub systems was based on the use of finlines, which, it may be recalled, were used to great advantage in the VPL backward wave tube work more than 25years earlier (Ch2).

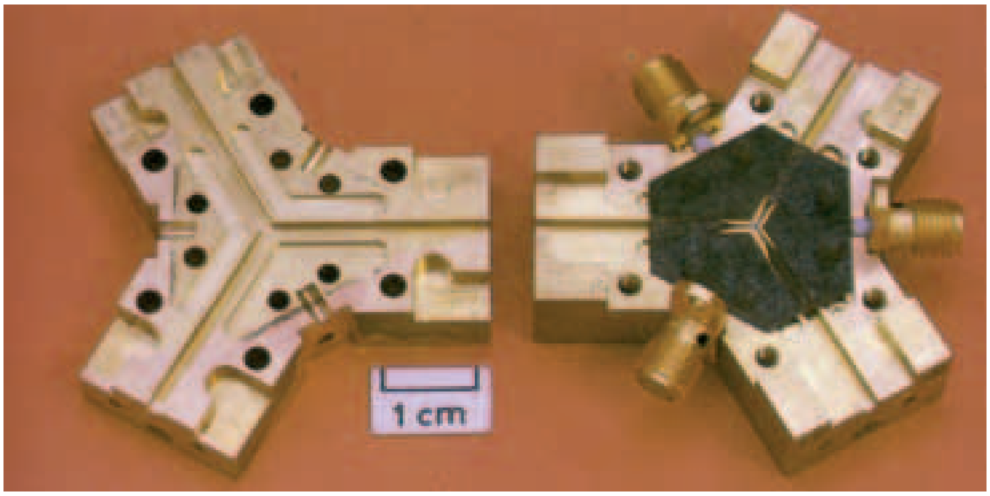
**Finline for MICs.**

The interest in finline derived from the realisation that it provided a readily made low loss transmission medium in the millimetric range, compatible with semiconductor devices such as beam leaded mixer diodes. The finline used was made from a thin dielectric substrate, bridging the broad faces of rectangular waveguide, on which metal fins and circuit elements could be defined using conventional thin film photolithographic techniques. The concept is illustrated here.




*A Finline circuit and Finline circuit elements*

Various millimetric components were made using this technique and these included filters, balanced mixers, directional couplers and PIN switches. A finline PIN switch, made for use in a Dicke radiometer in the 80-90 GHz range is shown opposite, with one half of the waveguide removed. It was designed to switch the input of a receiver between an




*80-90GHz Finline PIN switch*

antenna and a matched load.

*Mr. Bob Bates*

The concept was extended to the fabrication of other types of transmission line such as microstrip and a range of millimetric components were made; these included detectors, balanced mixers, harmonic mixers, PIN switches and attenuators, integrated radiometer heads and Gunn oscillators. This was a research sample fabrication facility and supplied samples to customers. The shape of things to come. Bob Bates, Mike Coleman, Steve Nightingale and P Ballard were the prime movers in this activity.

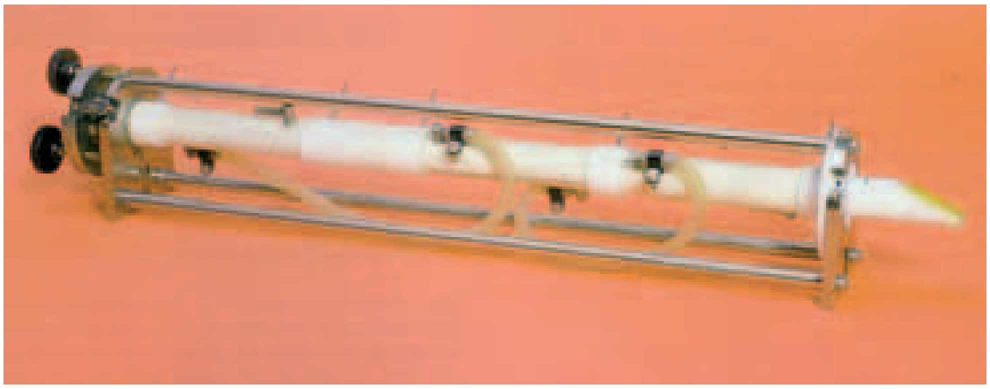
**TRAPATT Oscillators.**

A co-operative programme between Systems, SSE and Mullard Hazel Grove resulted in a marketable, stable TRAPATT oscillator. TRAPATT (Trapped Plasma Avalanche Triggered Transit) oscillators had been known for some years but interest in them had waned as it had proved extremely difficult to establish and maintain coherent oscillations from them.

A painstaking combination of device and circuit technologies, in the first place between SSE and Systems, resolved the basic difficulties. Thereafter further development involving Hazel Grove resulted in a device operating at S-band (3GHz) offering pulsed output powers in excess of 200W with a duty cycle of 3% and an efficiency of 30%. This was an intermittent activity extending over 2-3 years and concerned John Summers and Maurice Pierrepont of SSE, Bob Davies, Barry Newton and Peter Booth from Systems and Stuart Jones, M Waller and G Tubridy from Hazel Grove.

**Infrared Techniques.**

Following the 1981 restructuring the Systems Division acquired some infrared device programmes. These included a CVD supported project on $CO_2$ waveguide lasers which had been running in APD since 1974; it was complemented by another project directed at the realisation of a high speed, germanium based, acousto/optic modulator capable of operating at 100MHz. A sealed off laser providing 3kW 20ns pulses at 3kHz prf in a Q-switched mode was delivered to RSRE for optical radar applications in 1981. The device, a water cooled alumina waveguide laser having an internal diameter of 2mm is illustrated.



*$CO_2$ Laser*

*Dr. Alan Fox*

Pyroelectric* detectors were the subject of another project in this area. Based on materials work carried out in SSE by Tom Keve, David Annis and others this detector array used a ceramic material, manganese doped PLZT (Lead Lanthanum Zirconate Titanate) and achieved a very satisfactory performance as a room temperature infrared detector.

George Weston and Bryan Stocker were responsible for the laser work, Alan Fox, BW Nicholls and DG Simmons for the modulator, and Andrew Turnbull, together with Ray Hall, for the detector.

**Communications.**

The importance of research in communications generally increased significantly during this period. In the first years the work of John Palfreeman's Communications Group itself was strongly oriented towards acoustic surface wave devices for providing frequency selectivity in radar and communication systems at vhf and uhf. This work resulted in a range of professional ASW devices for filters and oscillators an area of work in which Bob Milsom took a leading role and indeed became a world authority. Later, as we have noted, the name

* *Pyroelectricty is the change in polarisation of certain materials when subject to a temperature gradient.*

of the Group was changed to Signal Processing and the work was more directed towards the use of analogue and digital processing techniques in radio communications systems. Other activities included a study of data protocols for radio communications and work directed towards the realisation of single chip, low power consumption, circuitry for application in pagers and mobile radio. One outcome of this was the realisation of an integrated, zero-IF radio paging receiver employing on-chip, gyrator based channel filtering. A modified version of this pager was taken up by Valvo (Philips Components) in Hamburg.

As these activities developed a new international activity was set up in the Project Centre, Geldrop (Netherlands) to develop a new mobile PMr. (Private Mobile Radio) transceiver – the "New Concern Mobile" (NCM). The zero-IF work became part of it with two engineers seconded to PRL from the product Group.

In the former Electronics Group, which became Radio Systems in 1981, the main emphasis was on the use of radio for mobile communications, in particular the economic use of the limited available spectrum. To this end there was a major programme on dynamic channel assignment (trunking) of small numbers of radio channels using microprocessor based techniques. Dr. Richard French's work in the radio communications area was recognised, most pleasingly, by the award of the 1983 Paul Adorian Premium of the IERE for his paper "Multi-Transmitter Data Systems" which was judged to be the most outstanding of the year in the communications category.

## FURTHER CHANGES AND SOME OMINOUS RUMBLINGS

In March 1983, to my great pleasure and surprise, I was elected to the Fellowship of Engineering (later the Royal Academy of Engineering)* and I like to think that this also gave some satisfaction to other members of the Laboratory. Peter Trier and Steve Robinson had achieved the same distinction some years earlier and Brian Manley did so in 1984.

At the beginning of 1984 Norman Goddard was offered the opportunity of retiring early, at the end of the year. He accepted the offer and, once again, we embarked on the process of finding a new Director for the Laboratory. This time the matter was the responsibility of our former colleague Brian Manley who, in 1983, had succeeded Wim de Kleuver as the member of the UK Group Board responsible for Research and Development. Obviously both Graham Cripps and I were interested in the possibility of succeeding Norman but in the event Keith Fuller was persuaded to leave Racal and return to Philips, which he had left in November 1981, as Director Designate of PRL. Norman

* *The Royal Academy of Engineering and the Laboratory's connections with it are discussed in an Appendix.*


*Norman Goddard retirement celebration*

retired with, due ceremony, at the end of the year and Keith Fuller took up the reins on 1st January 1985.

Also at the end of 1984 Mike Underhill accepted an appointment as Technical Director of MEL and was succeeded as Head of the Systems Division by R P Vincent who, in turn was followed as Leader of the Microwave Group by Bob Bates. Mike Underhill was a great loss to us; he was a man of outstanding technical ability and great managerial skill and sensitivity. In mid 1984 our Personnel Manager, Richard Turner joined Philips Business Systems in Colchester and Frank Stewart, formerly of Mullard Mitcham was appointed in his place.

During the Goddard era, which had been one of great achievement in the Laboratory, there had been a reduction in the total number of staff in the Laboratory from 582 at the end of 1975 to 517 at the end of 1984.

Although I had a great regard for Keith Fuller personally, I have to admit to having been rather disheartened by the turn of events. Also, as a result of some private conversations with Piet Kramer, prior to the appointment of the new Director, I was uneasy about what might be going to happen in the Laboratory in the new regime. Despite the undoubted success of the previous ten years one looked to the future with considerable misgiving.

## CHAPTER SEVEN

# TROUBLED TIMES 1985 - 1991

### AN AGEING LABORATORY

At the very beginning of this period doubts about some aspects of the Laboratory performance were being expressed by Piet Kramer of the Concern Research Management and others. Brian Manley, then the UK Group Board member for Research expresses the problem in the following way: *"Every organisation requires among its staff a balance of young fresh enterprise and older stable experience. By the 1980s it was evident that the balance at the Laboratories had moved too far in the latter direction. It was a problem in many similar industrial research organisations that had grown rapidly in the 1950s in response to the need to build the nation's technological base. To overcome it required skilful management to transfer staff progressively and appropriately from research into development, production and the many other opportunities for career development that existed in the Philips Group. By doing so the vigour of the enterprise could be maintained and the company as a whole benefit from the injection of high calibre staff entering through the research route. The failure to deal with this in a positive way over many years had resulted in an ageing Laboratory that, in my view, had lost much of the élan, enthusiasm and sense of urgency which had characterised it in earlier days and which presented a formidable barrier to promotion among younger, ambitious entrants. That view was shared by others who were dealing with the Laboratories as colleagues and customers. The evidence was clear that many of those younger people had left the Laboratories and the company within five years or so of joining. I believed that urgent action was needed or the Laboratory would rapidly lose its high reputation both inside and outside the company.*

*Dr. Brian Manley*

*The concerns of the Board in London were shared by the Concern Research Management in Holland and a programme of renewal was agreed with Keith Fuller, then Director Designate. The initial step was to make 50 of those closest to retirement redundant and to offer voluntary*

*redundancy to others over 50 years of age. Generous terms including pensions based upon service to full pensionable age were offered and agreed with the Unions. The second stage was to encourage the transfer of up to 50 staff to other parts of the Company. The third stage was to recruit 50 new scientific staff into the Laboratories. In order to avoid the recurrence of the problem new entrants joined with the explicit understanding that laboratory life was expected to be the beginning of a career in Philips that would see them progressing to other parts of the Group within a few years.*

*These were dramatic steps, but were a response to one of the most serious problems that had faced the Laboratory during its history, and one that was perhaps more evident to those outside the Laboratory than within it. It would, of course, have been more comfortable to have found a gradual approach to resolve the dilemma, but time had run out on the Laboratories"*

This then was the brief before Keith Fuller as he started his Directorship. His first task was to deal with the proposed redundancy operation. It was difficult, as there were many staff members who were in the prescribed age group. Some were in senior positions and their departure would have crippled the organisation, there were others without whom we could probably manage with difficulty and still others who were contemplating retirement with some pleasure and would probably welcome the opportunity of going early. As Brian Manley has noted the redundancy terms offered were attractive, particularly to someone having several years of employment but some years short of normal retirement. Nevertheless the operation received a very unfavourable press. Within the Laboratory too there were, understandably, some very unhappy people who felt that, having given their best years to the Laboratory and contributed notably to its work with more to offer, they were being ungratefully cast aside. The Unions, particularly ASTMS, were very angry and there were many meetings between their representatives and officials and the Company, including some of the most able and experienced negotiators. It was a novel and difficult experience. Eventually the Unions accepted the position and the redundancies were implemented in the course of 1985. With the benefits of hindsight it was perhaps unwise to have placed such strong and overt emphasis on the age criterion as it was that which really upset the staff, seriously damaged morale and created such a bad impression in the outside world.


"Fifty's a difficult age—young enough to rule Russia but too old for research"

*Financial Times 26 March 1985*

At the beginning of 1985 Graham Cripps, Peter Bunn and I were all over 50 but were not offered redundancy – some one had to keep the ship afloat! Several Group leaders, however, were made redundant (some voluntarily and some not) and left during 1985. Most of the staff affected left at the end of July 1985 and there was a massive farewell party in the Canteen on their last day. Peter Trier gave the farewell address and did it well but it was not a happy occasion.

In SSE three Group Leaders, Peter Daniel, Nick King and Eric Millett, left as did Ron Pratt, John Knowles, Charles Fuller, Reg Oldfield and a number of others. In Systems similarly three Group leaders John Palfreeman, George Weston and Brian Evans, together with Andrew Turnbull, Alan Fox, Jim Smith and others all left. The story in CVP was much the same with two Group Leaders, Alf Woodhead and Eric Snelling, going, whilst in Engineering several senior people, including Ian Lewin, David Tremlett, Reg Harriden, Charlie Grimble, John Marsh, John Sapp and about eighteen others also went. It has to be admitted that some of these were not unhappy about the turn of events. Harry Howden, who had had such an important role in several opto-mechanical activities retired quietly and normally, amidst all the mayhem, in May 1985.

Of these individuals John Palfreeman, Brian Evans and Peter Daniel accepted posts in the University of Surrey whilst Nick King was appointed to a Professorship in Renselaar Polytechnic in the USA. Renselaar had a particular reason for wanting Nick which was that they had recently acquired a high speed electron beam pattern generator as a gift from IBM and needed an expert in these machines to make it work! He made a great success of it. As far as I am aware the other Group Leaders involved simply retired, some of them bitter and resentful, and did not seek further employment.

The matter of staff transfer was another major part of Keith Fuller's brief. As Brian Manley has said, this was not something at which the Laboratory had been very successful over the years and Ray Peacock returned from Mitcham charged with dealing with the question. This was a difficult exercise for Ray, he achieved some success but, for us, transfer never became the smooth natural way of life that it was in the Nat Lab for example.

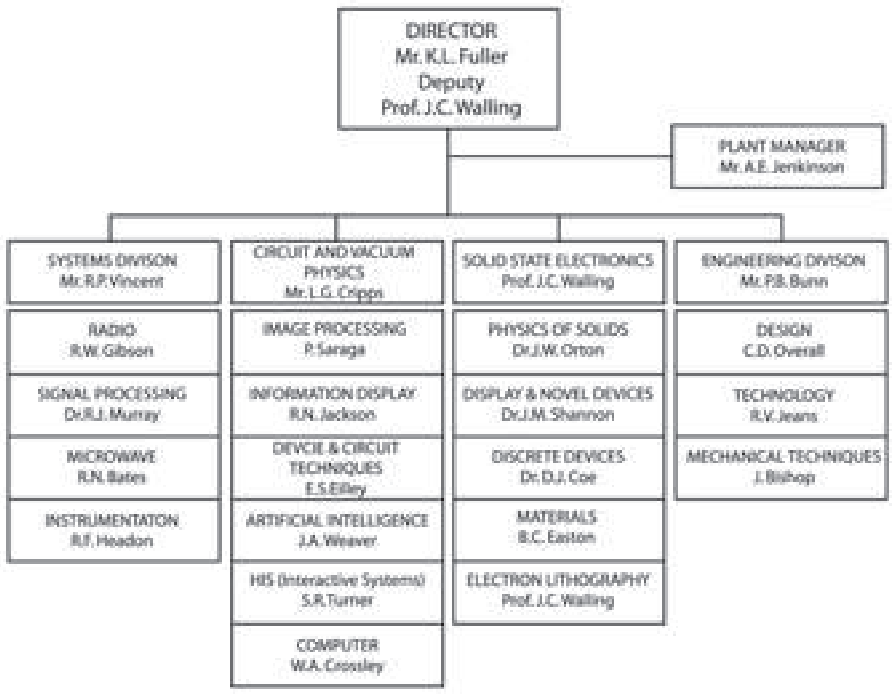
*Mr. Keith Fuller*

### LABORATORY ORGANISATION

The senior staff losses considerably affected the organisation and the programme of the Laboratory and it was necessary to regroup and redirect some of the activities. Although

this was not easy there were benefits to the Laboratory as the newly promoted individuals brought a fresh outlook and new enthusiasm to their tasks which was really very stimulating.

At the end of 1985 the re-organisation of the Laboratory was completed as follows:-




| | |
|---|---|
| Personnel. | Mr. F Stewart. |
| Financial Controller | Mr. JD Day |
| Plant Engineer | Mr. A Jackson |

Several changes took place in the course of the next few years although, with the exception of the Systems Division the basic structure remained essentially unchanged until 1991. The main changes and events were the following:-

In 1986 the name of the Circuit and Vacuum Physics Division was changed to the Informatics Division and John Shannon was appointed Deputy Divisional Head of SSE.

In July 1987 Graham Cripps retired due to ill-health and was succeeded as Head of Informatics by Richard Jackson, Tony Crossley becoming Deputy Divisional Head and Alan Knapp Leader of the Information Display Group. Graham had been a Divisional Head since

1963, he was very sound technically and a wise and visionary manager, he had made an enormous contribution to the Laboratory and his sudden death in October 1994 came as a great shock. Also in 1987 our Personnel Manager, Frank Stewart moved to Mullard House being succeeded by Miss Ann Redfearn. Further retirements were those of John Day, who was followed as Financial Controller by Zbigniew (Zbig) Kowzan, and John Bishop, Head of the Mechanical Techniques Department who was succeeded by Mick Martin.

In April 1988, on reaching the age of sixty, I was appointed Senior Consultant, a new role, being succeeded as Head of SSE by a member of the Nat Lab, Dr. JA (Bertus) Pals. Bertus had spent a year in the Division in 1973 and was well known to us, well liked and well respected; this was a good appointment. At the same time Jim Beasley became Leader of the Electron Lithography Group, formalising what had been the *de facto* situation.

At the end of 1988 the Systems Division was restructured, still under Richard Vincent, with new Groups viz:-

| | |
|---|---|
| Defence Systems | RJ Murray |
| Professional Systems | RW Gibson |
| Systems Technology | P Harrop |
| Simulation and Signal Processing | CB Marshall |
| Instrumentation | RF Headon |

Bob Bates left to join Pye Unicam as Development Manager and Bob Murray became Deputy Divisional Head.

In May 1989, on his sixtieth birthday, Peter Bunn retired and a new division, the Scientific Services Facility, comprising the Engineering Groups together with Instrumentation and the Computer Department, came into being under Ray Peacock. Coincidentally Ray was appointed an OBE in the Birthday Honours for that year. Tony Crossley was appointed to be Planning Manager – a new post; Joe Morice succeeded him as Head of the Computer Department and Peter Saraga (clearly on the up and up) took over the role of Deputy Divisional Head of Informatics.

Following my retirement in April 1990 Richard Jackson was made Senior Consultant and Peter Saraga appointed Head of the Informatics Division in his stead. Further changes in 1990 were that John Shannon was appointed Scientific Adviser and David Coe was made Deputy Divisional Head of SSE.

In 1991 Arthur Jenkinson retired and was replaced as Plant Manager by Gordon McGinty. Arthur was one of the first members of SSP and had been concerned, with notable success, with crystal growing, X-ray topography* and pyroelectric materials prior to his appointment as Plant Manager in 1970. Arthur was shrewd, firm and determined, an able and discerning scientist and an extremely competent manager. His early death, a result of a brain tumour, was sad indeed.

The all round performance of Philips in 1990 and in the immediate previous years was such as to prompt a critical review of costs in the Concern and expenditure on Research came under very close scrutiny. PRL was not excluded and this had huge consequences for the Laboratory programme. Of these the most immediate and, frankly, most dismaying, was that the outstanding, indeed literally world leading, work on Molecular Beam Epitaxy was terminated, the staff concerned, many of world renown, being made redundant. The work on military systems, so important a part of the Laboratory programme since the very beginning, was similarly brought to close. These changes however dictated the course of the Laboratory in its next phase rather than in this and we will discuss that in the final chapter.

## FURTHER CHANGES

There were several external changes during this period, which had a significant impact on the Laboratory. In 1986, Brian Manley became Chairman and CEO of a new joint Philips/AT&T enterprise in Europe, AT&T Network Systems Ltd., and his responsibility for Research as a member of the UK Group Board passed to Mr. W South. In 1987 Ivor Cohen resigned as Managing Director of Mullard Ltd and was succeeded by Dr. David Kynaston. Dr. Piet Kramer who had been Co-ordinator of Philips International Research for several years and was most supportive of the Salfords Laboratory retired in 1988 being replaced by Dr. Kees Bulthuis who had been seconded to MRL in 1968. Ir Harm Mooijweer who, as Director of the Concern Research Bureau, had been a great friend and colleague for many years also retired about this time being succeeded by Prof Feier Meier.

In 1988 Prof. Sir Roger Elliott FRS, Wykeham Professor of Theoretical Physics in the University of Oxford, who had been a Consultant to the Laboratory for almost twenty years, resigned. Roger had made a most valuable contribution to the theoretical work in SSE, in the recent years most particularly in relation to the MBE programme.

The Radio Mast, a feature of the Lab since its establishment and a local landmark but which had become completely redundant, was removed in 1988. ID cards were introduced

* *In that connection Arthur had spent some time in the University of Bristol working with Dr. Andrew Lang, the inventor of X-ray topography, he also spent a year in the sixties seconded to the Nat Lab.*

in the Laboratory in that year and great play (very politically correct) was made, outwardly at least, with the Laboratories' involvement with the CWQI initiative (Concern Wide Quality Improvement).

## THE PROGRAMME

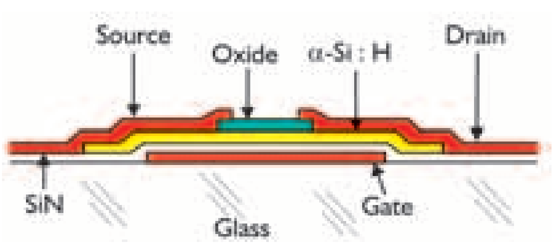
As we have seen this was a time of great changes in the Laboratory. Nevertheless, for the most part, it was also a time of excitement and considerable technical and scientific success for the programme, some of which we will now consider.

## THE SOLID STATE ELECTRONICS DIVISION

### Active Matrix Liquid Crystal Displays - AMLCD.

This programme was probably the largest and certainly one of the most important to the business of the Philips Concern ever undertaken in the Laboratory. It was concerned with research on the materials, devices, circuitry and technology necessary for the realisation of large area arrays of thin film transistors for use as pixel switches in actively addressed liquid crystal displays.

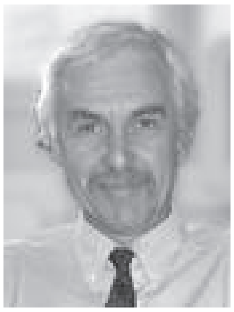
The PRL work actually started as long ago as 1979 when Martin Powell and John Orton, then in the Applied Physics Division embarked on an investigation of the properties of plasma deposited amorphous silicon ($\alpha$-Si). This material was prepared by a technique of plasma deposition first described at that time by Prof. Walter Spear and Dr. Peter Le Comber of the University of Dundee. Following the 1980 reorganisation the work was continued in SSE, largely in Eric Millet's Materials Group but with device work in the Physics of Solids Group headed by John Orton. This latter project was transferred, briefly, to the Materials Group in 1984. Initially several possible applications were envisaged only one of which was active matrix displays; the others included solar cells, vidicons and opto-couplers. Interest rapidly became focussed on displays, however, and in 1980 a joint project was started with the Nat Lab in which PRL were concerned with the $\alpha$-Si based active matrix and Nat Lab with the liquid crystal aspects. The application envisaged was that of an A4 datagraphic display within a ten year time scale. Reasonable progress was made and in 1982 a 64x64 element array of TFTs (Thin Film




*Cross-section of $\alpha$-Si:H TFT*

Transistors) for use in a LC display was realised. The TFT device is sketched on the previous page. A paper on the display was presented in Japan at the "Display 1983" conference but at the same meeting Sanyo demonstrated a 3" colour TV with a Liquid Crystal display. This sent a wake up call to the whole industry, including Philips, although there were (as ever) conservative elements within the Concern who questioned whether LCDs of the size required for real TV applications could ever be realised.

Nevertheless a decision was taken within Concern Research to make PRL responsible for a major LCD project directed at the realisation of a working LCTV. I remember Piet Kramer discussing this with Norman Goddard, Graham Cripps and myself in Norman's office, one evening in the autumn of 1984, and I have to admit being rather lukewarm on that occasion as I could see this project becoming very large and impacting, negatively, on other things which I considered to be of greater interest. As it turned out I was right on the first count and not entirely wrong on the second. The decision was made and announced in early 1985. The programme thereafter became the main activity of John Shannon's newly formed Display and Novel Devices Group there being four major projects, one of which, run by Stan Brotherton, was concerned with poly-Si as an alternative to $\alpha$-Si. Poly-Si became a subject in its own right and we will return to it. In addition to the work in SSE there was a project in the Information Display Group in Informatics on Circuits and Systems for LCTV. All told it was a big effort and was to get bigger.



*Dr. Stan Brotherton*

*Dr. Martin Powell*

Progress was good and by the end of 1985 2" diagonal monochrome displays having 108 columns and 96 rows had been made and demonstrated. Further success followed and by the end of 1986 a 6" diagonal colour TV display with 468 x 288 picture elements was made. A refined version was demonstrated at the September 1987 Eurodisplay Conference in London at the same time as Martin Powell presented a paper on "Liquid Crystal Displays for TV" which was awarded the prize for the best paper at the conference. This was, in fact, the largest high quality LC video display which had been demonstrated anywhere in the world at that time and was the first such display, of any size, to be made by a European Company – a tremendous achievement indeed. The display unit and a video picture on the 6" display are illustrated opposite.

In recognition of his truly outstanding work on amorphous silicon and liquid crystal displays Martin Powell was awarded the 1988 Paterson Medal and Prize of the Institute of Physics. We were all delighted at this and I felt considerable personal

*Video picture on the 6 inch display*

satisfaction that three of the first six recipients of this award were members of SSE.

Meanwhile, world wide interest in active matrix LCD was growing at such a rate that Philips Consumer Electronics together with Elcoma decided to set up a joint development activity in Eindhoven on LC TV. They also decided to focus their efforts on the $\alpha$-Si diode ring technology favoured by the Nat Lab rather than that of the TFT in the development of LCTV displays. Some work on the $\alpha$-Si diode ring technology in support of the development was undertaken in PRL and some exploratory work on MIM (Metal-Insulator-Metal) technology for active matrix switches was initiated. This latter was largely the brainchild of John Shannon.

The PRL technological capability was greatly enhanced by the purchase and installation (in a dedicated clean facility in G-block) in 1988 of an Anelva PECVD (Plasma Enhanced Chemical Vapour Deposition) machine. This machine was remarkably successful and provided all the deposited layers of semiconductors and dielectrics used in the active matrix research programme until its closure in 2004. The fact that larger machines of the same type were used in the Eindhoven development facility greatly facilitated the transfer of PRL technology to development. The transfer capability was further enhanced by the secondment, in 1988, of two people from PRL, Jeff Chapman and Mike Hemings, to the Eindhoven Development centre. After some years Jeff returned to PRL but Mike remained in Eindhoven as a member of the Flat Panel Display (FPD) Group. In the course of 1988 a 6" colour display using the $\alpha$-Si diode ring technology was made and demonstrated in PRL. The technology was successfully transferred to Development and the first such displays were made there in June 1989.

Despite increasing evidence that the $\alpha$-Si diode ring technology had significant disadvantages, due to its comparative inflexibility, the Development Group felt strongly that they should stick with the concept. The diode approach was initially attractive because the technology of making the diodes was relatively simple and the probability of row to column shorts was virtually zero because the row and column lines were on opposite sides of the liquid crystal cell. The main disadvantage was that, because several diodes (up to 12) were required in each ring, the switch was relatively large, taking up a significant area of the pixel. As pixel sizes diminished this became progressively more important. Philips, however, persisted with the diode approach until the mid nineties.

An alternative to the $\alpha$-Si diode was the MIM diode, as we have noted, and the technology of these devices for use as pixel switches was developed in PRL by Jeremy Sandoe, Ian French and John R Hughes. This work was rather successful and a 6" display using the technology, which had become known as the TFD – Thin Film Diode – technology, was demonstrated in mid 1989. There were some problems with uniformity of the MIM devices but these were circumvented by the use of a novel method of driving the displays known as five level drive jointly invented in PRL and the Nat Lab. The TFD technology lent


*David George with the HDTV Projector*

itself to the realisation of high resolution displays and was exploited in the construction of an HDTV projector, shown opposite which was completed towards the end of this period and exhibited at the Concern Research Exhibition in 1993, In the course of this work it became apparent that stray capacitance effects would set a limit to the image quality attainable with this technology. Nevertheless it was successfully pursued in development and production the resultant displays being used *inter alia* in laptop computers as shown here.

*Laptop Computer with a TFD display*

A key invention made at this time jointly by Alan Knapp and Rob Hartman (of the LCTV Development Centre) was "Overdrive". This scheme now widely applied in LCTV displays increases the response speed of the display by pre-processing the input signals thus allowing better reproduction of moving images without change in the display technology. Further work on improving the quality of moving images in AMLCDs was carried out by David Parker and Stephan Blitzakidis and involved novel techniques such as flashing the backlight.

*Dr. Alan Knapp*

From the very beginning of the work on AMLCD it was clear that poly Silicon was a possible alternative to a-Si as a material in which to make large arrays of thin film transistors. Indeed poly-Si offered significant potential advantages, in particular that material of higher mobility could be prepared and that both n and p type devices could be realised using it. This improved performance offered the enticing possibility of integrating the driver circuits with the display giving a substantial cost reduction. The big problem with poly in this application was preparing layers of it at a sufficiently low temperature to permit the use of glass substrates – essential for LCTV. In 1985 a programme, led by Stan Brotherton and involving Audrey Gill and Nigel Young and, later, Richard Ayres, was initiated in John Shannon's Group in SSE with the aim of developing the necessary technologies.

Initial work, concerned with directly deposited poly-Si on glass, was later expanded to include solid phase recrystallisation of pre-deposited $\alpha$-Si layers. Device work was also started and, in parallel, so too was work on circuit design using the devices; this design work was undertaken, in the main, by Martin Edwards of Alan Knapp's Group in Informatics.

Working row and column drivers in a CMOS technology were made during 1990. An important change in the material technology occurred with the introduction of Excimer laser recrystallisation of $\alpha$-Si. Laser pulses melted the silicon without significantly heating the glass substrate; the silicon crystallites, which resulted on cooling, had a low level of defects giving rise to high mobility without the need for plasma hydrogenation. A project on devices based on this material led to an in-depth understanding of the instability mechanisms and hence a technology and device architecture offering the possibility of making extremely stable devices became available at the end of this period

In parallel with the work on materials, technology and devices there was a programme in Informatics, led by Ken Freeman on the Simulation and Modelling of LCTV displays. There was also a further programme in the Auxiliary sector under the aegis of Norman Wright concerned with the engineering and packaging of LCTV Displays.

**Molecular Beam Epitaxy.**

For most of this period the molecular beam epitaxy work undertaken in the Physics of Solids Group continued with outstanding success before being brought to a premature close in 1990.

The growth facilities had been significantly enhanced in 1984 by the installation of a Varian Gen II machine and in 1987 another Varian machine, a Modular Gen II was purchased and brought into use. Together with the original Varian machine and the two PRL constructed machines we then had five growth systems in use. It was quite a facility and in the expert hands of Tom Foxon, Jeff Harris, Karl Woodbridge, David Hilton, Christine Roberts and, initially Colin Wood and John Roberts*, these machines were used to grow quantum well and 2-DEG (two dimensional electron gas) structures in the GaAs/GaAlAs system of the highest quality. The level of control of the growth of material and structures which was achieved led to very successful programmes of research into the physics and applications possibilities of these low dimensional structures – an entirely new class of electronic materials.

*Dr. Philip Dawson*

*Dr. Geoffrey Duggan*

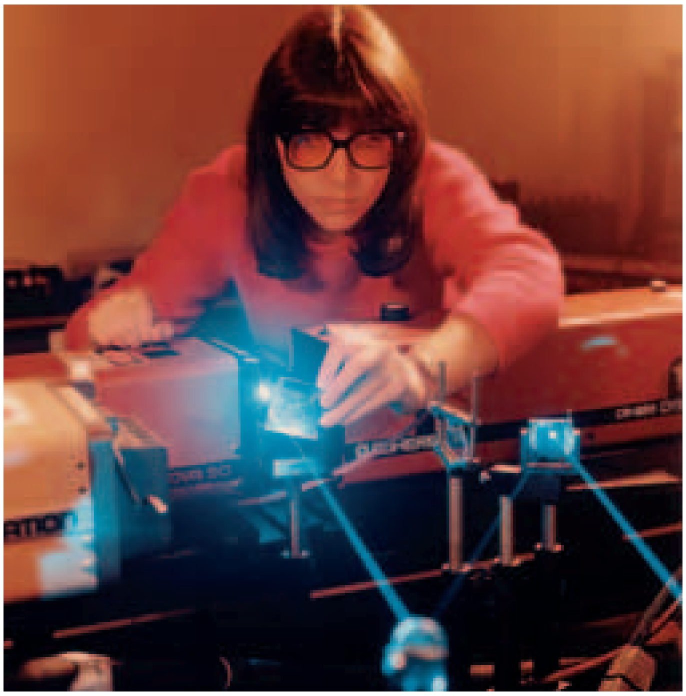
The first of these physics based programmes was concerned with investigating the optical properties of quantum well and superlattice structures and with the development of opto-electronic devices based on them. Phil Dawson and Karen Moore undertook the experimental work and co-operated with Geoff Duggan and Hugh Ralph in elucidating the underlying physical theory. They used the techniques

* *This John Roberts was not the same person as the John Roberts who was responsible for the Analytical Department in the Materials Group. He was an all round expert in epitaxy and left PRL to join the IRC facility in the University of Sheffield towards the end of the eighties.*

*Dr. Hugh Ralph*

of photoluminescence (PL) and photoluminescence excitation spectroscopy (PLE) to probe the optical transitions occurring in the structures and hence to determine the subtleties of the energy band systems within them. The alignment of the energy bands within the quantum well with those of the confining material was an important parameter both in understanding the physics of the quantum well structures and in device applications and was therefore extensively investigated. Time resolved measurements (very demanding experimentally) were used to determine carrier and exciton dynamics. The exclusion of oxygen from the structures was shown to be crucial to good optical quality and here the SIMS facility and the expertise of Barrie Clegg proved vital in detecting and measuring very low concentrations of oxygen. In addition to the work on the GaAs/GaAlAs system the optical properties of InGaAs/GaAs strained layer superlattices were studied and a number of phenomena observed unambiguously for the first time, confirming theoretical predictions. This was true band structure engineering.

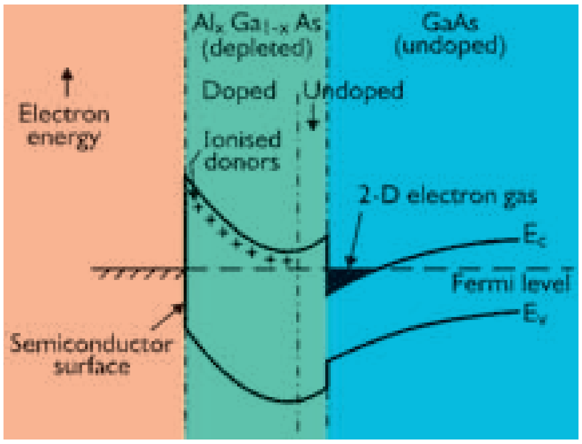
The main area of exploitation of the optical work in devices was that of quantum well lasers, the basic concepts of which were discussed in the previous chapter. At that time the viability of the QW concept was demonstrated through the realisation of a device operating at a wavelength of 707nm corresponding to well width of only 12 AU ie 4 monolayers. During this period Peter Blood and his colleagues, Dennis Fletcher and Paul Hulyer, built on the initial success, developing a close collaboration with Gerard Acket and his group in the Nat Lab, and realising ridge waveguide lasers having very low threshold currents. They also explored the advantages of replacing the GaAlAs confining layers with GaAs/AlAs superlattices. Existing models of laser devices were found to be inadequate in that they did not explain fully the observed characteristics of the QW devices and Peter Blood together with Alicia Kucharska, developed a complete computer model of the quantum



*Karen Moore making optical measurements*

well device. This successfully described the operational features of the device and was used to design quantum well lasers to a desired specification without resort to time consuming and expensive trial and error methods.

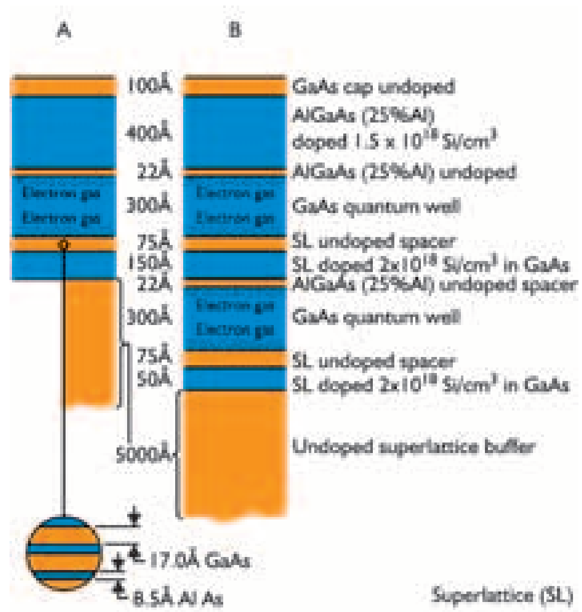
The second area of activity, dependent on the growth of high quality material and structures, was that concerned with the so-called two-dimensional electron gas (2-DEG). This can be formed in GaAs/GaAlAs heterostructures consisting of a layer of very pure undoped GaAs, followed by a very thin layer of undoped GaAlAs and then a thicker layer of GaAlAs into which dopant atoms of silicon are introduced. The energy diagram for this structure is sketched below, from which it can be seen that the electrons sit in a minimum in the conduction band on the GaAs side of the heterojunction. Here they are confined close to the interface but are free to move in the plane parallel to it – the origin of the term 2-DEG. The electrons are spatially separated from their parent silicon donor atoms and thus do not experience ionised impurity scattering and the growth process ensures that interface scattering effects are minimised. The electron mobility in such a structure is thus greatly enhanced. In PRL the team led by Tom Foxon and Jeff Harris carried out a detailed analysis of the factors limiting the mobility and, on the basis of this understanding, were able to grow structures in which the electron mobility had the highest values ever recorded for a 2-DEG viz: - > $10^7 cm^2 V^{-1} s^{-1}$ at 2K. The ability to produce material structures of this outstanding quality led to fruitful collaborations with a number of University groups including those of Prof Robin Nicholas in the Clarendon Laboratory at Oxford, Prof Mike Pepper FRS in the Cavendish Laboratory in Cambridge, Prof Lawrence Eaves FRS and Prof Laurie Challis in Nottingham and several others. Whilst our prime concern in these activities was to access the specialist expertise and facilities of the collaborators in characterising the structures, we shared their interest in exploring the detailed physics of the virtually perfect electron gas in the unparalleled PRL structures. This included the Quantum Hall effects and the tantalisingly elusive Wigner condensation in which the electrons are believed order themselves into a regular solid lattice. This was mind-boggling stuff at the very frontiers of solid state physics, Hendrik Casimir would have been thrilled and delighted, as indeed we were! Even today




*Energy band diagram for a 2-DEG structure*

these legendary Philips samples are cherished in those Universities lucky enough to have them rather like sacred relics in ancient cathedrals. It is worth pointing out that work in this field resulted in two comparatively recent Nobel Prizes in Physics. In 1988 we supplied some of the best 2-DEG samples (under a contract) to the National Physical Laboratory where they were used in a new determination of the Standard Ohm by means of very careful measurements of their quantised resistivity. This new standard gained international recognition.

Our principal motivation as an industrial laboratory though was more prosaic, we were concerned with growing structures for High Electron Mobility Transistors (HEMT). In these transistors the current transport from source to drain is by means of the electron gas in a 2-DEG structure. The limited electron density in such a structure however restricts the current density and therefore the power available from such a device. Our control of the growth processes was such however that we were able to prepare complex structures in which as many as four electron sheets in parallel provided the current transport. In effect this was a double quantum well structure, the arrangement and geometry being illustrated here. The structure was grown in the GEN II system and the device electrodes were defined by electron lithography, the gate electrodes being 150μm wide and 0.5μm long. At a frequency of 12GHz the device provided an output power of 89mW with a gain of 8.5dB and an efficiency of 41%. These were extremely competitive figures and, coupled with other positive features of the device, made the concept very attractive for power generation applications at millimetre wavelengths.




*2-DEG structures used in an HEMT*

Notwithstanding the very real performance advantages offered by both the opto-electronic and microwave devices resulting from the MBE programme they were not taken up by the product divisions, most probably as a result, at least in part, of the Concern-wide financial stringency of that time. As we noted earlier a further direct consequence of the financial problems was the decision, made in 1990, to terminate the PRL MBE programme

and to make many of the staff redundant. Whilst the main outward argument for the decision, the imperative need to reduce costs, was understandable, this was nevertheless a stunning blow, the work was in its prime, in no sense was it in decline, and from the scientific view point it was the most successful programme ever undertaken in the Laboratory. This is evident from the fact that in the five years from 1985 to 1990, almost one hundred papers on the work had been published from PRL and a further one hundred and thirty published jointly with our collaborators. In the outside world the decision was greeted with dismay and once again the Philips Research Management got a very unfavourable press. An item in the "Daily Telegraph" at the time headed "Philips axes electronics research team" goes on to say that "British research on the next generation of electronic materials has been hit by the announcement that a world beating team is to be disbanded". The author, Roger Highfield, then quotes Robin Nicholas (Oxford) in saying - "It is a major blow [to British science], we can't simply go out and replace the world leaders in the field".

Further and more positive evidence of external regard for this work was the award of the Patterson Medal and Prize of the Institute of Physics for 1985 to Colin Wood and that for 1991 to Paul Fewster. Also, in 1986, the IBM Europe Science and Technology Prize was awarded to Bruce Joyce*. (This latter, a most prestigious award, was shared with two other pioneers of epitaxial growth techniques.) Additionally Karen Moore was awarded a well merited Doctorate by the University of Twente in 1991 following her submission of a thesis based on her work at PRL. That the work of the team is not forgotten, even today, was demonstrated at the 13th International Conference on MBE in 2004 when Jeff Harris and Jim Neave were given the MBE Innovators Award for their discovery (more than twenty years previously) of RHEED oscillations in MBE growth. In addition at the same meeting, Tom Foxon received the Al Cho Award in recognition of his unique contribution.

*Dr. Bruce Joyce*

Following the termination, this most successful team was dispersed, many being made redundant. Bruce Joyce, who had started it all, had, however, been appointed Director of the new IRC in Semiconductor Materials and Professor of Semiconductor Materials in Imperial College in 1988, Peter Blood had accepted a Professorship in Physics in Cardiff at about the same time and Peter Dobson had gone to Oxford where he is now Professor of Electrical Engineering and a Fellow of Queen's College. Of those made redundant, John Orton and Tom Foxon took up Professorships in Nottingham, where David Lacklison joined them. Jeff Harris and Karl Woodbridge went to University College, London. Jim Neave and

* *Bruce Joyce was elected a Fellow of the Royal Society in 2000, being the third former member of the Laboratory to achieve this distinction. The others were Steve Robinson and Brian Ridley as we noted previously.*

Christine Roberts joined Bruce Joyce in ICST whilst Phil Dawson and Karen Moore went to Manchester, Phil to UMIST and Karen to Manchester Metropolitan University. Geoff Duggan joined the new Sharp Research Laboratory being set up by Clive Bradley in Oxford and Hugh Ralph went to ISA. The growth systems were sold, the modular GEN II to Nottingham, the wonderful GEN II itself to Cambridge and the PRL made systems to ICST. The GEN II, in which we had grown the world beating structures never performed quite as well again. Altogether this was a sad end to a remarkable chapter in the history of the Laboratory.

**Electron Lithography – The HISEL Project.**

In 1985 there was world wide interest in the possibility of using electron beam pattern generators on line in integrated circuit fabrication in a direct slice writing (DSW) mode. For this to be successful however a major increase in the writing speed of the machines was necessary. Nick King had been a staunch believer in DSW favouring the shaped beam route, also followed by Alec Broers and Hans Pfeiffer in IBM. The PRL Electron Lithography Group had been greatly reduced as a result of the 1985 redundancies however (these included Nick himself) and there was no way in which we could mount a new programme on a high speed electron beam pattern generator alone and unaided.

The Product Division, I&E, nevertheless were very interested and in May 1985 they were approached by one of their EBPG customers, Prof. Berghardt Lischke of Siemens (who had two Philips EBPG-4 machines) with a novel idea for a high speed machine. The essence of this was the generation of a linear array of individually programmed micro-beams, he envisaged as many as 1000, which could be scanned over the surface of a silicon slice. This concept was known as the Kammsonde (Comb Probe) and I&E, persuaded by Lischke's well developed arguments, were keen to see some work undertaken on it. There was however another approach, championed by Prof Karel vd Mast of the University of Delft, a former member of I&E and consultant to them, which was to use an array of high brightness electron emitters, the individual beams being programmed to form a sequence of shapes. This concept was known as the shower beam and the dynamic and persuasive vd Mast convinced I&E that it was at least as promising as Lischke's Kammsonde. Both Philips and Siemens were keen to see a high speed direct slice writer realised but, following the virtual closure of the PRL Group, neither had the resources in place to mount the research programme necessary to decide between the two competing approaches and build a

prototype machine. In February 1986 the two companies therefore came to an agreement jointly to support a co-ordinated programme of research in several German Universities and also in the University of Delft to explore the feasibility of the two concepts. The Philips funding was provided by Research (P Kramer) and I&E. Sizeable projects were set up in the Universities of Darmstadt, Tübingen and Delft, the Technische Hochschule in Berlin and the Fraunhofer Institute for Silicon Technology, also in Berlin. This big programme, known as the HISEL Project, was co-ordinated by a joint Philips Siemens Steering Committee on which Jim Beasley and I, together with various members of I&E, represented Philips. A lot of travelling was required and it always seemed to be snowing in Berlin.

In PRL we did some work on the p-n emitters for the shower beam. These had been pioneered by the Nat Lab and loudly (and prematurely) proclaimed by them as world leading electron emitters of super high brightness. In fact our experience of them was disappointing, as was that of Karel vd Mast, and even the Nat Lab were unable to reproduce their earlier results. This was most unfortunate and very seriously delayed progress on the shower beam in Delft, which depended on them. Some brilliant work was however done on the Kammsonde in Tübingen and in the two Berlin establishments, particularly in the Technische Hochschule where Professors Siegel and Christaller devised an efficient and practical means of dealing with the enormous amount of data demanded by the multibeam system. This was sufficient to demonstrate that the Kammsonde concept could have been developed to provide the basis of a viable high speed pattern generator. It was not further developed however as it had become apparent in the course of the project that direct slice writing was most unlikely to be required in main stream IC manufacture. Also by 1989 there were major financial problems in both Philips and Siemens, which resulted in the termination of the project in October 1989. Whilst not completely successful technically the project nevertheless provided a shining example of the possibilities of European multinational co-operation.


*Mr. Nick King and Mr. Jim Beasley at Jim's retirement*

Jim Beasley retired at the conclusion of the HISEL project and here Jim and Nick King, returned from Renselaar, are pictured at one of the parties marking the event. With Jim's

departure research into Electron Lithography in PRL came to an end. Let us be in no doubt however that the work of Nick and Jim and their many colleagues created a new activity for Philips which, over the years, generated business worth many millions of pounds.

**Power Devices.**

Following the re-organisation, which took place in 1985, the Power Device programme continued in the Discrete Devices Group of SSE and in the Device and Circuit Techniques Group of Informatics where Ted Eilley had a vital role. The main emphasis of the work was on the IPS (Intelligent Power Switch) technology and its applications. In this technology a power device was combined with a control system of logic built on the same silicon chip. This combination opened up market opportunities for semiconductor devices in areas formerly the preserve of electromechanical devices such as relays. A particularly exciting market area was that of the automobile and an active co-operation was established between PRL, Mullard Hazel Grove and Bosch of Reutlingen who enjoyed a virtual monopoly in the supply of electrical equipment to the German motor car industry. Using the PRL developed PIPS500 process several IPS units for automotive applications were constructed in the Laboratory and demonstrated at the Concern Research Exhibition in 1986 creating a great deal of interest. On the right we have a block diagram of an automotive switch - a typical IPS, and a micrograph of such a device - a TOPFET. Doug Patullo, David Paxman and Carole Fisher are pictured overleaf, symbolically removing the traditional wiring loom from a car and replacing it with an IPS system. The guiding

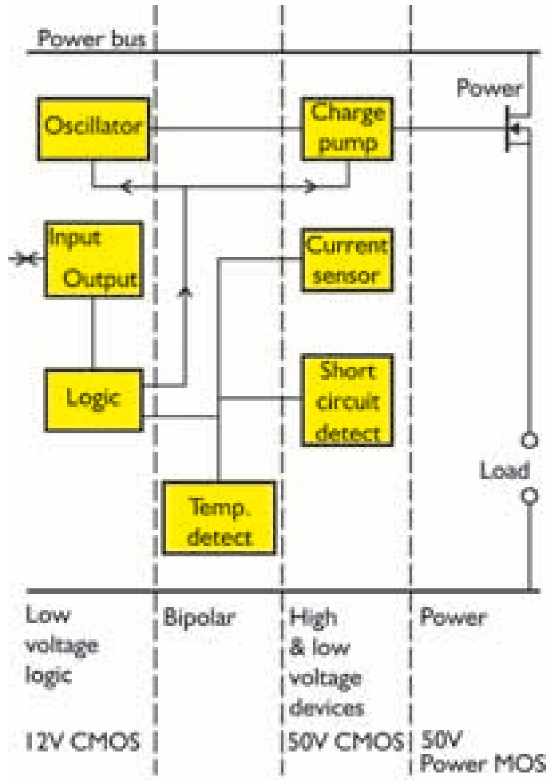
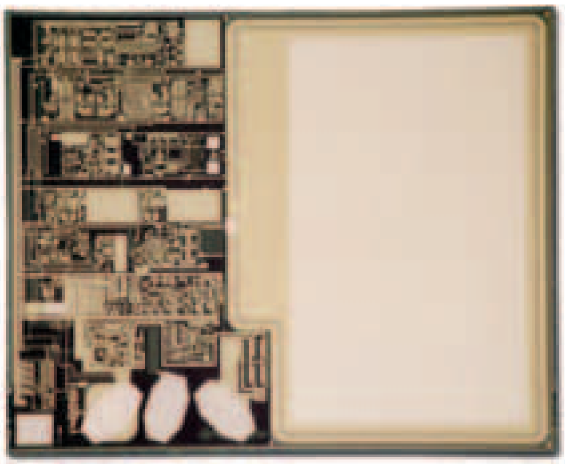



*Diagram of an automotive switch*



*Micrograph of a TOPFET*

principles followed in the development of the PIPS500 process had been the retention of all aspects of the self aligned DMOS process used in production to make the Power MOS device and the use of surface diffusion only to create the extra devices. This ensured that the performance characteristics of the basic power device were retained and that the process of making the intelligent power switch was basically compatible with that used in production. This approach proved to be eminently successful and Hazel Grove readily reproduced the technology, putting the first High Side Intelligent Switch, the BUK 196-60 into development in 1990.

*Doug Patullo, David Paxman and Carole Fisher re-engineering automobile electrics*

Work was also carried out on improving the Power MOS characteristics whilst retaining the ability readily to add the logic functions and this work, by Stuart Higgins and Carole Fisher, resulted in a factor of two reduction in the on-resistance per unit area of the Power MOS. A rather different approach, followed by Keith Hutchings, was that of trying to adapt the Trench FET technology used in Philips Laboratories in Briarcliffe. This offered even greater reductions in the on-resistance of the power device and the hope was that a common technology might be developed meeting both the European and US market requirements. This proved not to be possible initially as the US requirement was for more intelligence on the chip resulting in what was essentially a modified integrated circuit technology, with a high mask count, rather than the simpler, cheaper and more reliable,

modified power device technology of Hazel Grove. In later years though, notwithstanding the additional complexity, Hazel Grove adopted the Trench FET as its basic power MOS.

A notable consequence of the PRL research was that, using the IPS 500 process and the CAD routines developed in PRL, Hazel Grove were able to develop their own intelligent devices. One such was the TOPFET (Temperature and Overload Protected FET) released in 1992 - a successful co-operative development recognised in 1992 by the presentation of a TEAM award by Peter Saraga (then Director of the Laboratory).

In 1992, as a result of extreme financial constraints, Hazel Grove withdrew their support for the work at PRL with the result that it had to stop. This seemed to be something of a catastrophe at the time but in retrospect appears otherwise as over the twenty years of Power Device work at PRL the factory had been supplied with the know-how, tools and techniques necessary for the development of thoroughly up to date technologies and products so that they were, so to speak, self supporting. Hazel Grove remains active in Power Devices today but without the PRL input and support in that crucial period their survival would have been very doubtful.

Throughout this period David Paxman and his colleagues gave great attention to maintaining close liaison with the factory. They held regular meetings, had extended stays in the factory working with the development staff and generally took every opportunity of building strong personal relationships. Not the least important means of fostering the interaction was the Annual Device Symposium usually held in Salfords. This way of working proved most successful and is often cited as an exemplary method of organising Research/Development liaison.

## THE INFORMATICS DIVISION

### High Definition Television - HDTV.

A project of major importance in this period was that undertaken in Peter Saraga's Image Processing Group in Informatics on High Definition Television HDTV. This was the successor to the earlier, hugely ambitious, wide ranging, Hi-Fi TV work, which had been carried out jointly with the Nat Lab under the Jackson/Tan aegis. Whilst the aims of the new project were more limited than those of its predecessor they were nevertheless most demanding. They were essentially to provide the user with a more realistic viewing experience than was offered by the systems of the day through the provision of a larger picture area (40" diagonal), a widescreen presentation with a 16:9 aspect ratio, a doubling

of the horizontal and vertical resolution and an improvement in quality all round by removing artefacts associated with transmission systems.

An immediate problem was that the then existing transmission channels did not provide the bandwidth required to deliver an HDTV signal to the consumer. A bandwidth compression of some four times was necessary and its achievement was not easy requiring complex signal processing in both the transmission system and in the receiver. Algorithms were developed both for the bandwidth compression and the conversion of the 50Hz transmission field rate to a higher frequency in order to avoid problems such as flicker in the large area display. These were used in simulation studies but experimental hardware was also constructed. This work was undertaken as part of a major European co-operative project EUREKA EU-95 aimed at the development of MAC compatible transmission system. This imposed certain constraints insofar as the system was to be based on a source standard of 1250 lines,2:1 interlaced, a 50Hz field rate and a transmission format of 625/2:1/50.

*HDTV projector*

Elaborate simulation facilities were set up, three of the key elements being an HDTV video processing simulator, a projector and Telecine which was the prime source of HDTV pictures. The projection system, which used three 13cm diameter CRTs with a $1m^2$ screen is illustrated.

In addition to the simulation work, working hardware was developed in the course of the programme, in particular a system for the motion compensated conversion of pictures from a field rate of 50Hz to a flicker free display rate of 100Hz. David Parker and Gerard Fernando were mainly responsible for this part of the programme. In 1990 Peter Saraga* was awarded the IEE Blumlein Willans Browne Premium for his paper "Compatible High Definition Television". The people mainly concerned with this work were Peter Saraga, Ian Fagg, Tim Trew, John Morris, Mike Hulyer, Colin Bramich, David Hood and Clive Newcomb.

Although technically rather successful, this programme, like its Hi-Fi TV predecessor, was overtaken by external events, this time, perversely, because of a move away from MAC despite the so-called MAC directive. This was triggered by Texas Instruments' failure to make one of the crucial chips for the MAC system with the result that the all-important

* *In 1989 Peter had been appointed Visiting Professor of Electrical Engineering in Imperial College.*

SKY TV was launched by Rupert Murdoch using an existing satellite and the PAL system. Thus it all came to nought – at least so one might have thought but a very important and far reaching outcome was that the ground rules for 16x9 Widescreen format had been defined.

**CD-I, CDROM and Home interactive Systems.**

During 1985/86 the realisation dawned on Simon Turner of PRL that the Philips developed Compact Disc, which offered the consumer one hour plus of pure digital sound, could also act as a vast digital data store of 600 Mbytes. This could be any combination of text, pictures, graphics sound or software. In this form the ubiquitous CD became the CDROM – Compact Disc Read Only Memory.

*Mr. Simon Turner*

A whole series of applications was possible, ranging from electronic reference books to interactive adventure games. To give an idea of the potential the full Oxford English Dictionary contains only 230 Mbytes of text and the Encyclopaedia Brittanica is only slightly larger at 280Mbytes.

Turner and his colleagues set out to explore the possibilities and as an experiment created part of an English language dictionary (the letter O) and put it onto a CDROM. This was the world's first multimedia CDROM. As a dictionary it was better than the paper version in that many of the entries were supplemented by a colour picture and most also had the pronunciation as an audible output. There were also acronyms and synonyms and related words. The reproduction system was comparatively simple consisting of an adapted consumer CD player interfaced to a home computer (very basic in those days) driving a colour display. Selection of an entry could be by touch selection from a scrolled list or by direct keying. The experiments, successful and exciting, hinted at the tremendous potential of the concept and demonstrated that a new interactive medium was at hand – the true beginnings of Multimedia.

Simon Turner and his team established a co-operation with Eric Schylander in Eindhoven and with the French Laboratory, LEP, and came up with the idea of a consumer interactive disc version of CDROM that would work with pictures and eventually video. The work came to the attention of Richard Bruno, whom Simon describes as a wildly enthusiastic Canadian, who was then in Philips Consumer Electronics (CE), but was subsequently appointed as Technical Director of a new Philips Business Unit – Home Interactive Systems. Bruno set out to exploit the concept in new products but first made

it his business to agree world standards with the Japanese manufacturers Sony and Matsushita. CD-I, a very big thing, was thus born. PRL was the centre of Philips activity and expertise and after five or six years of intensive research and development CD-I came on to the market in 1992. It was one of the high profile "President's Projects" and thus was personally endorsed by the President of the Company, then Mr. Jan Timmer. The development of the system with its support tools and range of titles entailed a very close interaction between the PRL team and the Interactive Studios, which had been set up in Dorking (to be close to PRL). Coincidentally, the Marketing Director for CD-I was another Simon Turner!

A very interesting development was that of Photo-CD in which 35mm negatives were recorded digitally on a CD and displayed, as high quality positive images, on a domestic TV set. This was a co-operative venture between Philips and Kodak and the additional functionality undoubtedly greatly added to the appeal of CD-I systems. This was a first step towards the introduction of a consumer version of writeable CD discs

*CD-I and Photo-CD*

Although technically a brilliant success, the CD-I venture was not commercially successful despite the fact that over one million systems and over fifteen million discs (plus many more Photo-CD discs) were sold worldwide. There was a problem with the available titles in that there was a lot of educational and cultural material with some games on offer, whereas what the consumer wanted was games and more games and video material. There was more than a touch of *déja-vu* about this if one recalls the competition between VHS and Video-2000 (technically the superior system). Sony, whilst supporting CD-I, were also busy developing Playstation I and there was no reason why they should not do so. This was launched in 1994 and Philips unfortunately missed the market.

In parallel with the CD-I work there was a large project in the Laboratory, led by John Morris, aimed at the realisation of Full Motion Video so that it would become possible to

* *MPEG = Moving Picture Expert Group*

have films on CD. This resulted in the creation of the MPEG 1* Full Motion Video Standard, which in May 1991, was stabilised as an international standard. PRL members, John Morris in particular, took a leading role in the relevant international standardisation committees and were largely responsible for writing the complex specification of the standard. This was work of critical importance in the evolution of Digital TV.

The CD-I work forms a fascinating piece of PRL history; it broke new ground for the Laboratory in that we had never before moved so rapidly from a research concept to the consumer market place. Although CD-I was not a complete success it nevertheless took the Company forward towards DVD and Digital Television. Many people were involved at various times, these included Simon Turner himself of course with Norman Richards, David Penna, Denise Bland, John Morris, Keith Johnson, Ian Fagg and a number of others.

**Artificial Intelligence – AI.**

During this period there was a big effort in the Informatics Division on Artificial Intelligence, that is the development of computer based systems having the ability to reason and to solve problems in a more or less human fashion. The object of the PRL work was to find ways of incorporating AI methods into future Philips products so that they would become easier to use and more user friendly. Some thought was also given to the possible applications of AI in the factories.

A major project in the area addressed the problem of communicating effectively with Intelligent Knowledge Based Systems (IKBS), perceived as being a serious bottleneck. This project was known as the BEES Project (BEES = Better Explanation in Expert Systems) and was aimed at developing general purpose tools for providing explanations tailored to the needs of users. How successful it all was is hard for me to judge, but it kept going in those difficult days so somebody must have been convinced by it all!

Some real and immediate problems were addressed though and these involved the development of computer languages LYDIA and ABLE which were useful in dealing with machine-machine interactions. AI techniques were applied to consumer products, CD-I in particular, an example being a cookery advisor system designed for CD-I. This and other applications of a similar nature were hailed with enthusiasm by both HIS and Consumer Electronics.

*Mr. Tony Weaver*

Those involved in this work included Tony Weaver*(Group Leader), Dr. Donia

* *Tony Weaver had worked in this general area for many years. He was expert, enthusiastic, articulate and incredibly resilient - an inspirational leader!*

Scott, David Connah, Peter Wavish, Richard Cole, Tom Wachtel, Phil Lloyd, Jennifer Jerrams-Smith, CJ Watkins and others.

AI techniques were also invoked by Systems Division during this period in connection with ESM signal processing. This was concerned with the de-interleaving of radar pulse trains and systems for the implementation of these techniques using transputers* were proposed, although it doesn't seem that any were actually made.

## THE SYSTEMS DIVISION

### FMCW RADAR – PILOT

One of the last projects on Radar Systems to be undertaken in PRL was that on FMCW Radar. The advantages of FMCW (Frequency Modulated Continuous Wave) are threefold. Firstly the use of high peak power pulses with their attendant complications is avoided, secondly the range resolution can be varied at will by appropriate choice of the frequency sweep employed and thirdly the systems have excellent ECCM (Electronic Counter-Counter Measures) properties. The rapid processing of FMCW signals was made practicable by the advent of Fast Fourier Transform processors and the availability of solid state microwave power sources capable of delivering several watts of CW power.


*Mark Barret with the FMCW radar system*

The principle of FMCW radar is fairly simple. The transmitter frequency is modulated with a repetitive linear sweep, the reflected signal is then at a different frequency from that being transmitted at a given moment because of the time delay to and from the target. Mixing the transmitted and reflected signals then gives a beat frequency directly proportional to the range of the target.

A 3W X-Band system was built jointly by PRL and Hollandse Signaalapparaten, Hengelo. This had a solid state CW transmitter and exhibited a sensitivity equivalent to that of a pulse radar of the same mean power, a greatly superior range resolution and vastly better ECCM performance, that is to say that it was virtually undetectable. This latter

* *The Transputer was an IC chip made by INMOS, a Microelectronics Company initiated and subsidised by the UK Government. It provided both memory and logic functions but failed to compete with the microprocessor.*

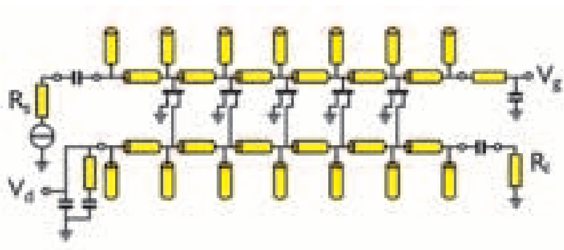
characteristic made it very attractive and the system was developed and produced jointly by Hollandse Signaal and PEAB (Sweden) and called PILOT – Philips Indetectable Low Output Transceiver).

FMCW systems operating at 94GHz using varactor tuned Gunn oscillators were also constructed in PRL and tested at RSRE Pershore.

Andy Stove and Patrick Beasley* were mainly responsible for the FMCW radar work in PRL.

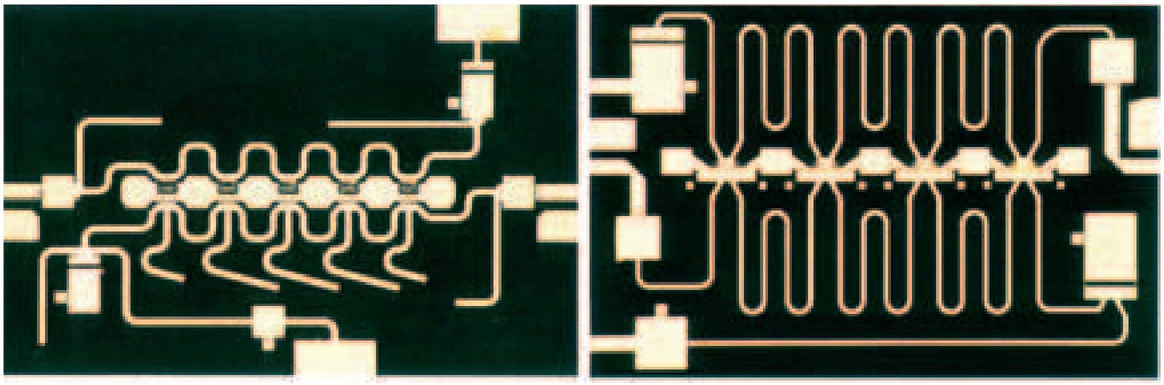
**Monolithic Microwave Integrated Circuits (MMICs).**

During this period some outstanding work was carried out in the Microwave Group in co-operation with Philips Microwave Hazel Grove on the fabrication of monolithic microwave integrated circuits. Those primarily concerned at PRL were Bob Bates (until his move to Pye Unicam) and Brian Minnis, while Steve Battersby, David Vinton and others assisted with the device fabrication. Stuart Jones and Chris Buck were the Hazel Grove participants. The main focus of attention was on distributed microwave amplifiers based on GaAs FETs. The basic amplifier consisted of a pair of low-pass filters between which FETs are connected at regular intervals. This concept is illustrated schematically here. The filters used were synthesised as distributed element structures by an exact transfer function procedure, which appears to have been a great advance. Several wide band amplifiers of impressive performance were constructed, one of the first used Avantek FETs in groups of three in a module giving a gain of 5dB over the 2-18GHz band. Eight of these modules cascaded on to a single substrate gave a gain of 40dB, flat to within 3dB over the same frequency band – very impressive. The same design philosophy was followed to realise an amplifier giving 5dB gain over the 18-26 GHz band; this used six 0.25μm gate length GaAs FETs made at Hazel Grove and PRL. The gates of these devices were defined by electron lithography at PRL. Another amplifier employed four 0.7μm gate length GaAs FETs and gave a gain of 10dB over the 2-6GHz band; four of these chips cascaded gave 40dB gain. The basic chips for the 18-26 GHz and the 2-6 GHz amplifiers are illustrated overleaf. This was a very powerful technology and the resultant devices found application in the fields of electronic warfare and radar. To a former electron tube man they were truly amazing. Some



*Distributed amplifier topology*

* *Patrick is the son of Jim Beasley of Electron Lithography fame. He is now at Qinetiq Great Malvern (formerly RSRE)*

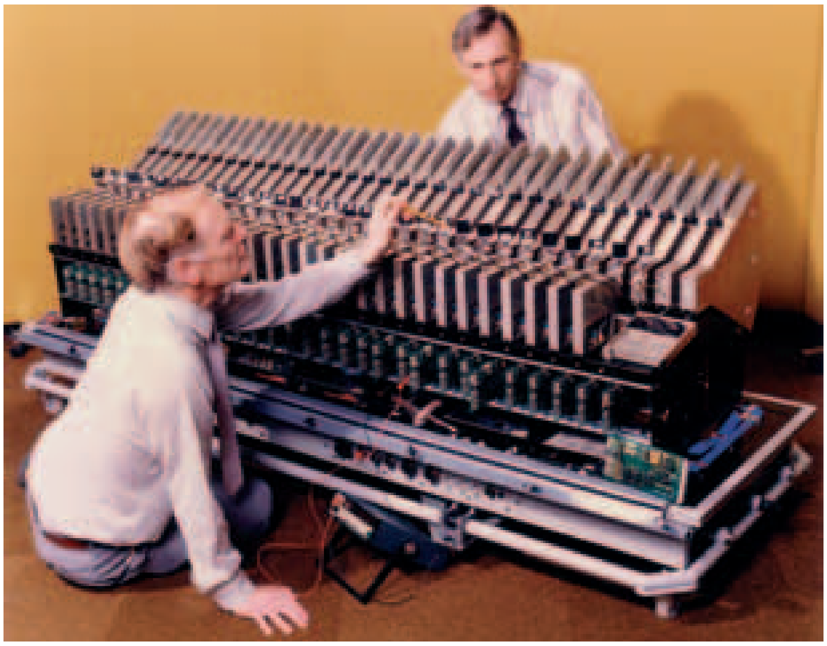


*MMIC chips for the 18-26 GHz and 2-6 GHz amplifiers*

aspects of the technology were taken up by Philips Microwave Limeil (PML) in France and further device developments took place as part of a directly funded programme for a Swedish Philips Company CelciusTech. This enabled CelciusTech to obtain a major Swedish Government development contract.

**Phased Arrays.**

Phased array transmitters and receivers are systems in which the signals transmitted from or received by the array add in one direction only. They were of considerable interest to radar engineers particularly in the context of multistatic radars* and FMCW systems. An experimental one dimensional array was constructed at PRL and successfully used in a bistatic configuration with the Gatwick Air Traffic Control Radar. Phased arrays were also of interest for FMCW radars. Peter Mallinson, Keith Salmon, Peter Massey and Ray Johnstone were those primarily concerned with this venture.

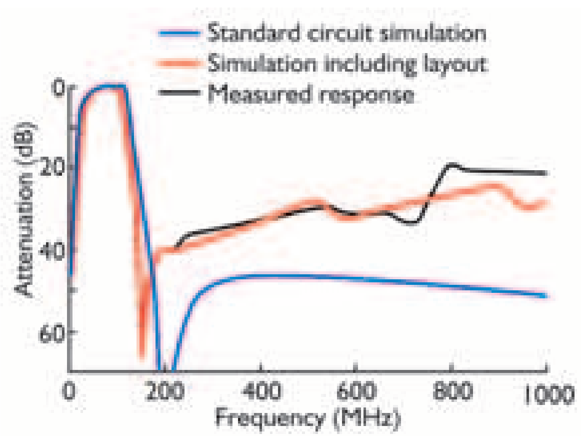


*Ray Johnstone and Keith Salmon calibrating a one dimensional phased array*

* *The simplest case of a multistatic radar is a bistatic system which comprises one transmitter and one receiver which are some distance apart.*

**Communications.**

In the initial part of this period a lot of work was devoted to the development of a method of simulating the performance of circuits in real hardware embodiments. Particular attention was given to circuits implemented on printed circuit boards (PCBs) and the problem was approached from a very fundamental stand point in that solutions to Maxwell's equations were sought for the extremely complex configurations of conductors and dielectric layers forming a PCB. The resultant program was known as FACET (Functional Analysis of Circuits by Electromagnetic Theory) and was able to analyse circuits in single sided (with a ground plane), double sided or multilayer PCBs and hybrids. The underlying mathematics was formidable but the program worked well and enabled substantial savings in costly and time-consuming hardware iterations of new designs to be effected. An example of the application of the program to the design of an RF filter on a PCB is shown in here, the agreement between the calculated performance and that observed being quite remarkable. This truly splendid piece of work was carried out by Bob Milsom and Kevin Scott.




*Response of an RF filter calculated by FACET*

A re-appraisal of receiver architectures was undertaken in the Simulation and Signal Processing Group, headed by Chris Marshall, as a result of which it was recognised that it might be possible to develop a zero-IF receiver capable of satisfying the requirements of the DECT (Digital European Cordless Telephone) Initiative. The zero-IF or direct conversion receiver offers an alternative architecture to that of the familiar superheterodyne receiver. In a zero-IF receiver the incoming RF signal is mixed down to baseband by tuning the local oscillator to the signal carrier frequency. A second mixer fed with a local oscillator signal in phase quadrature to that supplied to first mixer is necessary to distinguish frequencies equally spaced on either side of the carrier. In such an arrangement all the amplification and filtering takes place at baseband which makes it very suitable for integration since the channel filtering can be implemented with readily fabricated low pass filters. In the superhet the filtering takes place at IF and is usually performed by a crystal filter, which is not easily integrated. The zero-IF approach proved eminently successful in the DECT application and

an EEC funded joint program was established between PRL, the Nat Lab and Philips Semiconductors in Caen to develop the concept. A two chip zero-IF solution was developed, the chips being the UAA2078 and the UAA2079 which were employed in the Philips XALIO cordless telephone.

Another co-operative programme was established with part of the German Philips Group, Philips Kommunications Industrie in Nurnberg this being the German arm of the product division concerned with PMr. (Private Mobile Radio) equipment. Their interest was in GSM* base stations and they were using a receiver architecture that compressed the wanted signal using a logarithmic amplifier rather than an AGC arrangement. Logarithmic amplifiers extant at the time exhibited poor temperature stability; the PRL team, however, had previous experience of the design of sophisticated logarithmic amplifiers for military applications and were able to design two high performance logarithmic amplifiers which met the German requirement. These were industrialised as TDA8780 and TDA8781.

The Group made further contributions to the GSM programme under the framework of a "President's Special IT Project" in co-operation with Philips Kommunications Industrie and Philips Semiconductors (Signetics) in Sunnyvale, California. This activity resulted in a design for a two chip transceiver for GSM, code named SQUASH I and II which were eventually industrialised as SA1620 and SA1628 and used in the FIZZ mobile telephone which was the first "all Philips" product to enter the market. For reasons of expediency the receiver was not zero-IF and further work was undertaken in PRL to realise a near zero-IF receiver for the system. Eventually (mid 90s) this did make it to the market place first in a DECT embodiment (ONIS) and later in a GSM handset (XENIUM).

The work of this Group was similar to that on the Liquid Crystal Displays in that it was carried out in very close association with the relevant product groups and contained rather little basic science. It thus was in tune with what seemed to be a Concern wide move away from the Philips traditional style of Research in the direction of product development. As we will see this was a trend that was set to continue.

**MORE CHANGES**

In the course of 1991 Philips decided to sell the defence companies which made up the DCS (Defence and Communications Systems) Product Division and the Board increased its pressure on the Research organisation to reduce its costs and numbers. These developments had a major effect on PRL in that the main justification for the work on

* *GSM = Groupe Spéciale Mobile*

military systems was removed. This work, which had provided the main *raison d'être* for the System Division was therefore stopped and the majority of the staff made redundant. These redundances were, of course, in addition to those of 1985 and 1990.

Thus during Keith Fuller's directorship the Laboratory was reduced in size from 517 at the end of 1984 to 240 at the end of 1991.

In his early years as Director, Keith Fuller, very sadly, developed Parkinson's disease. Whilst initially the symptoms were not too severe, indeed Parkinson's was not diagnosed for some time, the disease progressed and it became obvious that he would not be able to continue as Director. At the end of 1991 therefore Keith was nominated as Chairman of the Laboratory and Peter Saraga was appointed as the next Director; these appointments became effective at the beginning of 1992.

In 1986 the Laboratory marked its fortieth anniversary by holding Open Days in June of that year. These were by no means our first Open Days (others having been held at roughly five year intervals since 1957) but they were probably the best planned. Peter Trier, Norman Goddard and Kurt Hoselitz all attended and are pictured below in the Director's office with Keith Fuller.

*Four Directors, Norman Goddard, Kurt Hoselitz, Keith Fuller and Peter Trier*

Two other pleasant and significant events took place during this difficult period, although unfortunately, because of their timing, they were rather overshadowed and passed almost unnoticed in the Laboratory. These were the elections of Norman Goddard and

Keith Fuller to the Royal Academy of Engineering. Norman being elected in 1985 and Keith in 1987.

In the course of 1991 the Laboratory was reorganised, yet again, this time into two scientific divisions, Solid State Electronics, with two Groups, and Systems which had four Groups including Display. The re-organisation became fully effective in 1992 and we will discuss it in the next chapter.

## CHAPTER EIGHT

# A DIFFERENT WORLD 1992 - 2002

### THE SIXTH LABORATORY DIRECTOR

Peter Saraga, who took up the role of Director of the Laboratory in January 1992, graduated in Natural Sciences (Physics) from the University of Cambridge in 1964 and later that same year joined the Laboratory as a member of the Systems Division. For many years thereafter he worked with Tony Weaver and his colleagues in the field of optical character recognition and its subsequent development and applications in factory processing and packaging involving automatic techniques. This was all rather successful and in the 1985 re-organisation Peter was appointed Leader of the Image Processing Group in Circuit Physics (which shortly afterwards became Informatics).

*Mr. Peter Saraga*

Peter's main concern in that capacity was with the HDTV project, pursued as part of a major European co-operative project. In the course of this work he demonstrated notable managerial and diplomatic skills. These were further evidenced during a six-month secondment to Philips House in 1989 in the course of which his work and all round capability clearly attracted very favourable attention and he was promoted to Deputy Divisional Head of Informatics on his return to Salfords in July of that year. Also in 1989 he was appointed Visiting Professor of Electrical Engineering in ICST and received the IEE's Blumlein-Browne Willans Premium for a paper on HDTV. In mid-1990 he became Head of the Informatics Division in succession to Richard Jackson.

The period to be covered in this chapter was one of great change and considerable difficulty within Philips as a whole; the Laboratory's *modus vivandi* was to be completely changed and its very survival called for a Director of vision and determination. Peter Saraga's appointment was timely and well considered but, nevertheless, the way ahead was going to be very difficult.

**RESEARCH FUNDING**

Since the beginnings of Research in Philips it had been funded by means of a levy on the turnover of each of the Product Divisions. The levy varied from one PD to the next but was generally about two per cent. The levy caused dismay in new acquisitions, such as the Pye companies and this, in 1969/70, prompted the composition by Peter Daniel of a poetic essay beginning thus:-

*A director of Pye, I recall,*
*Whose demands were not modest at all,*
*Said "I pay two per cent,*
*Which I deeply resent,*
*And the tune I must certainly call"*

*The Laboratory Chemist said "Why,*
*To please you we'll certainly try,*
*But if the needs that you voice*
*Don't fit with our choice*
*Our Veto we'll have to apply!"*

The research programme was determined in the light both of world scientific trends and of the current and potential requirements of the Product Groups as perceived by Research in discussion with the PDs, the decisions regarding the nature and scale of the various programmes being made by Research Management. Each year the members of the Concern Research Bureau made a visit, extending over several days, to each of the Research Laboratories during which the next year's programme was reviewed in detail and the funding agreed. It was generally a fairly amicable process.

At the beginning of the 1990s all this changed and a new funding regime was established. In the new scheme a major part of the Concern funding of Research was to be on the basis of contracts agreed with the Product Divisions, a much smaller part was to be long term research and it was expected that some external funding would also be sought and obtained. The notional breakdown of funding was then as follows:-

| | | |
|---|---|---|
| Concern Contract Research | – "Contract Research" | 65-70% |
| Concern Long Term Research | – "Company Research" | 25-20% |
| Self Funding Activities | – SFA | 10% |

That represented the original intention but Peter Saraga has pointed out that in practice the amount of Concern Long Term Research funding in PRL varied between 25% and 35% and in some years was as high as 40% over the whole of Philips Research.

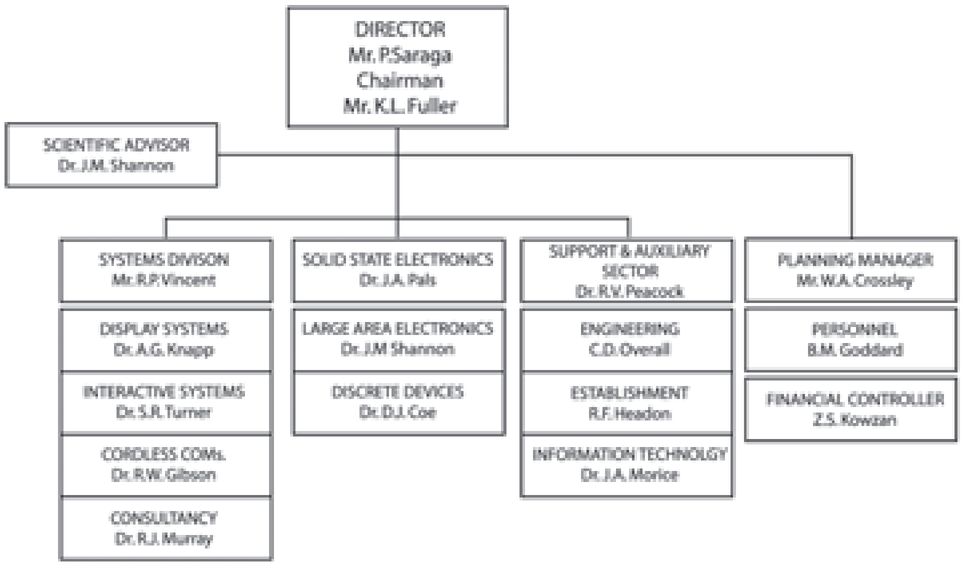
The Product Divisions were encouraged to make use of the Research organisation and for Research close interactions with the Product Divisions became very necessary for its survival. A great deal of effort was thus expended in determining the needs of the Product Divisions and in formulating research contract proposals in conjunction with them to meet those needs. The resultant draft proposals were submitted for approval to Concern Research management. It was not surprising that, since Philips Research comprised several laboratories in different countries, there were often competing proposals. To ensure that judgements were made on technical merit and not on local cost variations the concept of "One Research, One Rate" was introduced, that is to say that the notional rate per man employed was the same in each of the Philips Laboratories. Whilst competition between the Laboratories was discouraged co-operation between them was strongly encouraged and proposals involving more than one Product Division were considered very desirable. The procedure for obtaining Contract Research support eventually became known as "Process Zero".

This completely different way of operating evolved in the course of 1990/91 and was effectively in place when Peter Saraga formally took office at the beginning of 1992. Contract Research proposals were formulated in the main by the Group Leaders and Project leaders together with members of the Product Divisions. This, inevitably involved considerably more travel than had previously been the case and another consequence was a tendency to focus attention on the achievement of milestones and short term aims. One could say that the whole character of the Laboratory changed radically – it was indeed a different world.

## LABORATORY ORGANISATION

The staff reductions and the changes in the way of working dictated major organisational changes and at the beginning of 1992 the Laboratory was organised into two scientific divisions and a service division as set out overleaf.

A number of events took place during 1992 and the first half of 1993 which dictated changes in this scheme. These were:- firstly that Keith Fuller took early retirement in 1992, secondly that Bertus Pals returned to the Nat Lab in June 1993, thirdly that John Shannon relinquished his Group Leader responsibilities, in order to concentrate on his scientific work, and fourthly that Zbig Kowzan accepted an appointment in Eindhoven and was replaced by Keith Kirby.




Keith Fuller's early retirement was to a large extent due to his health problems and it is sad to note that he died suddenly on 30th December 2002.

Bertus Pals had spent five years as Head of the Solid State Electronics Division during which time he filled the role with great distinction and made many friends. Peter Saraga decided not to replace him but rather to take on the task himself being ably supported in that role by John Shannon as Scientific Adviser. Steve Battersby assumed responsibility for Large Area Electronics.

A further change which took place before Bertus Pals returned to Holland was that the pattern of work in the Discrete Devices Group changed dramatically following the decision of the Product Division to discontinue support for the Power Device programme, as we noted previously. The name of the Group was changed to Software Engineering and Applications reflecting the nature of its new activity. It was decided to locate the new Group in the Systems Division and to move the Display

*Senior management team January 1992*
*Back row, from left: Bertus Pals, Zbig Kowzan, Brian Goddard, Ray Peacock, John Shannon, Tony Crossley.*
*Seated from left: Keith Fuller, Peter Saraga, Richard Vincent.*

Systems Group to SSE thus reversing the rather strange earlier decision to separate Display Systems from the Large Area Electronics activity. A rare event, which took place shortly before Bertus returned to Holland, was that a photograph of the SSE Division was taken - a nice memento for him it appears below.

*Bertus Pals and Solid State Electronics Division June 1993*

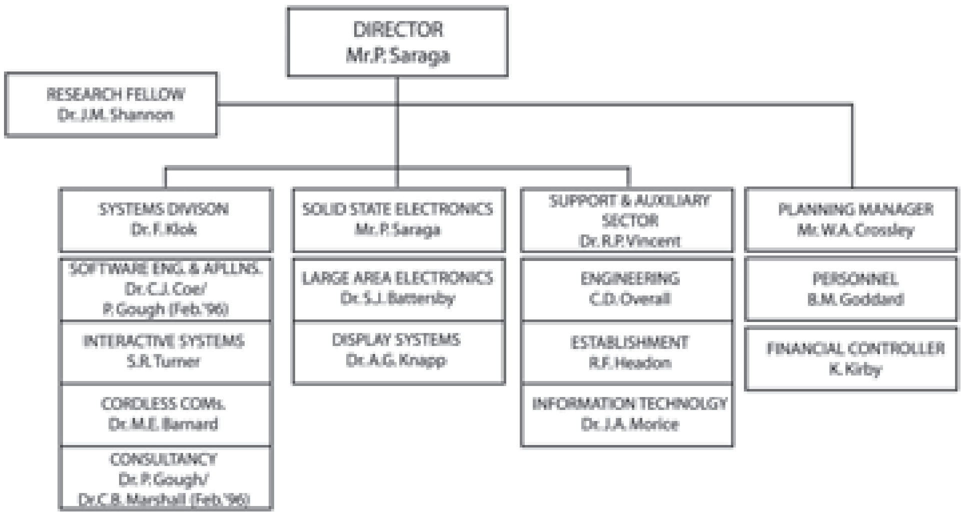
At the end of 1994 John Shannon accepted an appointment as a Professorial Research Fellow in the University of Surrey and an arrangement was made for him to divide his time between the University and PRL as a Research Fellow. At the same time John relinquished his responsibilities as Scientific Adviser.

Ray Peacock formally retired in 1995 and early in 1996 he was replaced as Head of SAS by Richard Vincent, making a lateral move. At the same time Dr. Fopke Klok of the Nat Lab, was appointed to head the Systems Division.

At the beginning of 1996 then the Laboratory was reorganised, acording to the scheme set out overleaf:-

Keith Kirby retired at the end of February 1997 and was replaced as Financial Controller by Brian Lugg. Tony Crossley also retired in September 1999 and was replaced as Planning Manager by John Cosier who, many years previously had been a member of the Laboratory, indeed he and I had worked together in my Section of SSP in the early 60s.

In August 1998 Fopke Klok returned to Eindhoven and following his departure the former Systems Division was divided into two new Sectors. These were the Wireless Sector, headed by Mike Barnard, which comprised the Cordless Communications and Consultancy Groups, and the Software and Interactive Systems Sector headed by Simon




Turner. The latter comprised the Interactive Systems and Software Engineering Groups. Similarly a Large Area Electronics Sector headed by Alan Knapp comprising the Display Systems and Large Area Electronics Groups was formed. Each of the three new Sector Heads remained in charge of his original Group.

The style of the management of the programme changed. The erstwhile Programme Planning Committee became the Technical Management Meeting, the members of which were recognised as the Technical Management Team. With time the membership of the Team broadened and eventually it comprised the Director, Sector Heads, Group Leaders and the Planning Manager. There was a strong emphasis on milestones, deadlines and costs.

In the later years of this period it became recognised that the pressures introduced by the emphasis on Contract Research, especially the drift towards short term work, were resulting in a failure to maintain the balance of capabilities necessary to sustain longer term work. A balanced all round capability had been one of the outstanding features of Philips Research in the past and Concern-wide steps were taken to restore the situation by the introduction of a system of Capability Management in the various laboratories. This was closely co-ordinated and featured strongly in the work of the Technical Management Team.

## THE LAST NEW BUILDING

During 1993/94 a new building, J Building, was completed to the south of G-block. As is evident from the photograph it is wholly different in style from the other buildings on the South Site but it was sufficiently well regarded locally to be given an award for architectural

merit by the Reigate and Banstead Borough Council in 1997. The building was intended to accommodate the parts of the Services and Auxiliary Sector remaining on the North Site, primarily the Engineering Group, and the transfer was successfully completed in the course of 1994. Towards the end of the 1990s the North Site was sold and is now occupied by Titan Travel Ltd who have retained B-Block, greatly altered, but have demolished A building, the original Laboratory building.

*J Building*

In September 1993 a time capsule was buried under J building which reminds me that when A Building was being substantially altered in 1955 (or thereabouts) a similar capsule was buried in one of the walls and it should have come to light during the demolition of the building.

At the beginning of this period a transformation of the interior of the South Site buildings (other than J-Building) was put in hand. The long, dimly lit, rather drab corridors, sternly functional and not very welcoming, were carpeted and equipped with sparkling bright lighting and new doors with coloured panels. Things were certainly brightened up although I think that the colour scheme, which makes extensive use of magenta, turquoise and blue, is probably not to everyone's taste. New furniture, in an elegant light wood and uniform style also appeared. It is all very different but whether the quality of work benefited or not, I cannot judge.

With the reduction in numbers, which had taken place, there was a lot of spare space available and over the years various other Philips UK Departments have moved in to the site. These are: the Advanced Projects Group, now known as Philips Applied Technologies and headed up by Bob Bates, a former member of the Systems Division, which arrived in May 1992; the Patent Department, now known as Philips Intellectual Property and Standards and led by Robin Boxall, in March 1994 and Philips Semiconductors. Research is now one of the smaller activities on the site.

*Philips Redhill Site June 1997*

**THE PROGRAMME**

In this new era, the nature of the work undertaken was more directly concerned with the creation of new products than had been most of that previously undertaken in the Laboratory. The programmes were thus pursued in close collaboration with the Product Divisions who were now quite explicitly "paying the piper". Although basic, long term research was possible, to a limited extent, in the new regime it does not seem that very much work of this nature was undertaken in PRL. The main areas of activity were those discussed in the following sections.

**SYSTEMS DIVISION**

**The Interactive Systems Group.**

This Group continued its activities, under the leadership of Simon Turner, in the Multimedia sphere, which, in the early 90s was perceived by Philips (and its competitors) as representing a market ripe for expansion. PRL, through this Group's previous activities had demonstrated outstanding capability in the field and had earned an excellent reputation. Several Product Divisions, including Philips Media, Digital Video Systems (DVS), Philips Semiconductors and Sound and Vision, were therefore anxious to place contracts with Research and indeed quite early on the Group were allocated more work than they could comfortably handle – the price of success!

Initially CD-I, on which Philips Media was almost totally dependent, was the main focus of the work of the Group, which then numbered almost forty people. There was a lot of work both on content, in which the presentation and design of things like games and "hands on" movies were considered, and systems, in which attention was given to the next generation of both hardware and software.

As we mentioned earlier, alongside the CD-I work, and to some extent complementary to it, there was a big programme, headed by John Morris, aimed at the realisation of Full Motion Video on CD. In 1992 the Group made the first twenty Video CD titles in their TV studio, an achievement made possible by the expertise of Derek Andrew and Ian Fagg in the area of high speed digital signal processing which resulted in world leading coding quality. The project employed what were then state of the art signal processors and CD writers but, notwithstanding, picture encoding and writing was four times slower than real time and the process was nerve-rackingly unreliable. Video CD based on this work emerged as a commercial product and was extremely successful in China where, it appears, VHS, for obscure political reasons, did not have a presence. The push towards higher bit rates and higher resolution brought about a revised MPEG international standard, MPEG2, and a new optical disc specification using MPEG2 was prepared, jointly with Sony, aimed at the realisation of a 2.5 hour film on one disc with a substantially improved picture quality. John Morris again wrote a large part of this specification, which was called MMCD – multimedia CD. Although technically this was a very satisfactory standard Philips and Sony were upstaged, on the world scene, by the DVD standard developed by Toshiba, Matsushita and Warner. All was not lost however as the patent position secured by PRL for Philips in this area was very strong and as a result one third of all DVD licence revenue accrues to Philips.

Philips rapidly adopted the DVD standard and PRL was commissioned to produce the first discs to be launched in Europe in the new format. To this end more than one million pounds worth of encoding equipment was installed, various enhancements being made, and the first 15 Philips, Polygram, titles were produced in the Laboratory; these exhibited the world's best picture quality.

The major challenge in this area emerged, however, as being not so much in the traditional research fields of concepts, technology and systems but rather in the enhancement and widening of the experiences to be derived from systems based on these new, but conceptually stable technologies. Simon Turner's group rose to the challenge experiencing a major culture shift in the process and recruiting designers and artists* to

* *In the first place these were students from the Royal College of Art who spent varying periods of time in PRL. Later a few such people were employed directly in partnership with Philips Design, in the main they were young women, bringing a new element of excitement to the Lab,according to the Director!*

further their cause; close ties were established with Philips Design. It was a different world indeed. Amongst the results of the new activity were the world's first interactive movies where the viewers was able to choose the outcome of the plot to suit their mood, they also developed a sort of interactive fantasy world, having pseudo characters and relationships, and the first Video on Demand. This latter was realised jointly with the Helsinki Telephone Company; it was a broadband system based on ADSL (Asynchronous Digital Subscriber Link) equipment and was the first demonstration that such a system could work using ordinary telephone lines. This was, of course, years before the emergence of the World Wide Web as we know it today.

Further work on Television hardware continued with the design, construction, evaluation and, thereafter, small-scale production of a Digital TV set top box employing the Philips Semiconductors Tri-Media chip. This set the standards for such devices and demonstrated some very advanced, unique and exciting features. A Personal Video Recorder using a hard disc was made in 1998 and this too was a world first. Set top boxes and PVRs for digital TV are now becoming increasingly familiar items and they all employ Philips patents which resulted from this work.

The team of designers and engineers brought together to create new interactive activities ran into funding problems in 1997/98, as a consequence of some retrenchment on the part of Philips Media, and began to explore alternative areas of work. One such, which developed remarkably, derived from the outlandish idea of incorporating electronic devices into clothes and became known as Wearable Electronics. The programme started in the Interactive Systems Group but in 1999 transferred to the Software Engineering and Applications Group. Its novelty and interest justify its being discussed separately.

The record of achievement of the Interactive Systems Group during this period of bewilderingly rapid technological evolution was quite remarkable by any standards. In many areas they were the acknowledged world leaders defining the standards which others followed; we can say, without fear of contradiction, that they changed the thinking, not only of Philips, but also of the whole world in this vital area of 21$^{st}$ Century electronics.*

**Software Engineering and Applications.**

This Group came into being in 1993 following the discontinuation of the Discrete Devices work, which we mentioned previously. This presented an opportunity for the creation of a new group to enable PRL to play a larger role in the rapidly growing area of

** Simon Turner took early retirement from PRL in April 2004. His farewell party was attended by many people including Mr. David Jordan, then very recently retired as Chairman of the UK Group Board and Dr. Rick Harwig, Head of Philips Research, giving some indication of the esteem in which he was held.*

software research. Peter Saraga's strategy in this was fully supported by Kees Bulthuis, at that time the International Research Co-ordinator, allowing a measure of relaxation in the pressure on numbers so that some redeployment* and recruitment were possible. Thus there was an increase in numbers to meet an important requirement, sending out a very positive message about the future to the Laboratory.

The broad remit of the new group strongly reflected the interests and capability of David Coe, the Group Leader, and also those of Paul Gough who was to succeed David as Group Leader in 1996. The mandate of the group, however, was less sharply defined than had been that of the earlier device work, being to develop and deploy world class capabilities in front end software and systems engineering. The programme was seen as being complementary to that pursued in the IST (Institute for Software Technology) headed by Dr. R Bourgonjon in Eindhoven who was, apparently, keen to see such work undertaken in the UK. By 1995 the work of the Group had become concentrated in three main areas viz:- Requirements Engineering (what should a software system do?), Usability Engineering (how does the user want it to behave?) and Validation, Verification and Testing (does it do what we want?). In Requirements Engineering the Group did pioneering work with Philips Medical Systems in Radiotherapy and X-Ray diagnostics, developing techniques which are now very widely used. In Usability (or User Interface) Engineering they did work on bridging the gap between Philips Design and software development and in Testing they undertook a range of activities including automated system testing of TVs and DVD players.

In 1996 David Coe left the Laboratory and was succeeded as SEA Group Leader by Paul Gough. Coincidentally the Group's formal links with IST were severed and new programmes were started in user interfaces for mobile devices; this work was carried on as part of a EU programme, FLIRT, and trials were undertaken in Helsinki, regarded as being NOKIA's backyard.

As we have noted Simon Turner's Wearables programme moved in to this Group in 1999 but by that time the two groups had formed the Software and Interactive Systems Sector under Simon Turner and the programmes thereafter developed along closely related lines.

**Wearable Electronics.**

This was one of the strangest activities to be conceived, endorsed and executed in PRL. It had its beginnings in Simon Turner's Interactive Systems Group following the expansion

* *Amongst the former members of Discrete Devices, David Paxman and Carole Fisher joined the AMLCD activity and Ted Eilley went to the Interactive Systems Group where he was concerned with the Photo-CD project.*

to include artists and designers in the search for enhanced video experiences and other alternative applications of electronic devices. Amongst the designers recruited at that time (c 1996/97) was Clive van Heerden who joined PRL from Thorn EMI and he it was, who, together with David Eves, conceived the idea of embedding electronic devices in clothes. The idea gained a measure of credence and a pilot project was started. The merging of clothes and electronics demanded skills in both areas and, whilst well resourced in electronics, the Lab was a bit weak in the other sphere. Thus a Fashion Designer, Nancy Tilbury, was brought in from the Royal College of Art, so too was a Textile Designer, Philippa Wagner, (it's all utterly mind boggling but read on) and work began on generating concept garments to illustrate how clothes with embedded electronics might look. To gain further credence within Philips and to demonstrate the concepts Simon Turner (who had something of the impresario in him) persuaded the organisers of the 1998 Concern Research Exhibition to let him stage what amounted to a fashion parade involving bright lights, loud music and lightly clad model girls. It was an all ticket show and a sell out.* It also had the desired effect of raising the level of awareness and understanding of the activity and of securing agreement for its expansion.

*Levi/Philips jacket inset MP3 player, remote control, Xenium phone, microphone and ear-phones*

A press release in August 1999 created enormous public interest and Philips was approached by several garment manufacturers keen to explore the concept further. One of these was Levi Strauss with whom an agreement on the development of a wearable product to test the market was reached. The electronic devices involved were a mobile phone and an MP3 player. These clipped

* *Those present apparently included Frits Philips himself who, though rather infirm, always attended the exhibition. I can't imagine what he thought of it all.*

into special pockets and were operated by a common remote control, a microphone and earphones were wired into the jacket and the whole system was interconnected by a flexible and washable wiring loom woven into the jacket. The design of the latter was difficult, stretching the ingenuity of both the engineers and the fabric and fashion designers. The mobile phone employed was a Philips Xenium with a voice addressed dialling system, which had been developed in the Cordless Communications Group. A nice feature was that if the phone were activated the MP3 player would automatically be turned down.

The original arrangement with Levi was that 2,500 such jackets would be made and the Laboratory had made the necessary large investment in devices. At a fairly late stage Levi reduced the number to 800, which were duly made but PRL was left with many sets of components, although not as many as might have been had the programme not been very carefully managed. A press launch for the jackets took place in Eindhoven in July 2000, representatives of both fashion and electronic journals being invited. It was a spectacular event generating huge interest and quite disproportionate publicity which transformed the image of Philips – probably for the first time they were considered "cool" by the young! Sales, despite the high price (£900 each to the customer) were impressive, encouraging Levi to request a set of Spring/Summer garments. These were duly designed by Nancy Tilbury working with the Levi designers and used up the surplus stock in the Laboratory, no doubt to the great relief of the Director.

Despite the publicity success no Philips Product Division was prepared to pursue the concept and to fund further work in Research, as a result Ad Huijser (the Philips Board Member responsible for Research) decided that the work in PRL should stop. That was almost the end of the story except that in 2001 the sports equipment manufacturer Nike became

BBC NEWS

You are in: Sci/Tech

Wednesday, 16 August, 2000, 00:02 GMT 01:02 UK

**'Techno' clothing hits high street**

Techno-clothing could bring health benefits

The world's first commercially available electronic clothing is about to go on sale in high streets across Europe.

Clothes equipped with fully integrated computer networks have been designed and developed in a joint venture between clothing company Levi's and electronics company Philips, following three years of intensive research.

The clothes, which could become the essential fashion of the future, enable the wearer to be fully connected to the world wide web at all times.

Jackets equipped with a mobile phone, a portable audio device, a remote control panel, a microphone and headphones, will cost about £600.

The clothing was first previewed this year at the Brave New Unwired World Fashion Technology Show in London.

Advanced technology could rob people of their privacy

*Press release which appears on the BBC web site*

interested in the possibility of building a heart rate monitor into a sports bra and Philips CE decided to take it up and to fund some work in PRL. A team led by Paul Gough and including David Eves, Matty Bickerton and Moritz Waldemeyer was assembled and at the 2003 Research Exhibition the system they had developed was exhibited. This consisted of a wireless heart rate monitoring sports bra with fabric electronics and a jacket containing a flexible display enabling a graphical presentation of the heart rate. CE however decided not to pursue the matter further and the wearables activity finally ended in mid 2004.

This is a truly astonishing part of the Laboratory's history; as one steeped in the traditions of Philips Research over very many years, however, I can only say *"C'est magnifique, mais ce n'est pas la guerre"**

**Cordless Communications.**

This Group undertook work for a wide range of Product Divisions and Business Units within Philips and this resulted, inevitably in a degree of fragmentation of its programme; efforts were made to minimise this, however, by identifying common requirements and running combined projects. As time progressed the emphasis of its activity shifted from communications as such towards "cordlessness" implying that the programme should be in the areas of Mobility and Connectivity. The reduction of power consumption in mobile products was rightly considered to be very important and so too was a continued involvement with the various international standards bodies.

*XENIUM handset and view of the inside*

A major project pursued at this time was that on Integrated Radio Transceivers in which advanced receiver architectures and technologies were developed for various wireless products including GSM (Groupe Spéciale Mobile) and DECT (Digital European Cordless Telephone). The results of this work were fed directly into development programmes in Philips Semiconductors (Caen). Notable successes were the implementation of the zero-IF radio architecture in to DECT (the XALIO handset) and the implementation of near zero-IF (NZIF) architecture into both DECT (ONIS handset) and GSM (XENIUM handset).

The work of the Group continued in this sort of vein

* *Marèchal Bosquet Remark on the Charge of the Light Brigade 1854*

stimulated by the predicted "convergence" of cellular, broadcast, WLAN and positioning services into products that can do almost anything on the move. This concept is illustrated below.


*The notion of convergence*

There were various organisational and personnel changes which took place in the Group during this era and we have already noted some of these. In particular the bringing together of the Cordless Communication and the Consultancy Groups to form the Wireless Sector under the leadership of Mike Barnard who, when he left to join PDSL in Paris in 2002, was succeeded by Neil Bird. Neil left in September 2003 to take up a post in the Nat Lab being succeeded by Tobias Helbig.

**The Consultancy Group.**

The formation of the Consultancy Group was a very interesting idea. It had its origins in the fact that at the time when Philips was divesting itself of its Defence interests in 1989/90 several defence contracts were in being in PRL; these were largely with former Philips companies and Government funding bodies. It was agreed that these contracts should be completed provided they were fully funded and in addition several enquiries had been received from third parties about the possibility of making use of PRL expertise. It seemed that a viable business might be established and to this end the Consultancy Group was formed at the beginning of 1992. An immediate benefit was that its formation to some extent alleviated the severe staff cuts resulting from the Concern's withdrawal from the military systems area. Initially the Group consisted of about 15 members of staff, it was accommodated on the site, and had access to all the support facilities; its continued survival

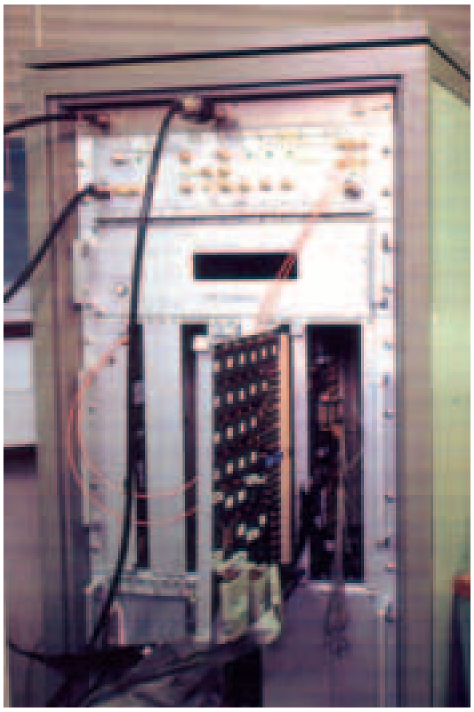
*The Consultancy Group in 1992*

though was conditional upon its being totally self financing and showing a 20%pa profit. The nature of the work undertaken was to a large extent determined by the expertise of the group, being initially at least, very strongly systems oriented. Bob Murray was the first leader of the Consultancy Group and one can only admire the skill, determination and entrepreneurial flair which he displayed in so successfully filling the role.


*Consultancy Group publicity material*

The Group operated as a real business, producing its own marketing material shown here and putting in the sales effort necessary to win new contracts. The turnover was around £1.5M pa

The valuable contracts with Hollandse Signaal and Celcius Tech in phased arrays and multistatic radar continued whilst other contracts included a DRA funded programme for 4W microwave power amplifier modules and a DTI contract, HEMPA, for high gain, high efficiency microwave power amplifiers.


*CODIT equipment with one PCB on show*

The largest single activity, which extended over several years was a Eureka contract called CODIT (Code Division Testbed). In this programme a system demonstrator (the testbed) comprising a mobile station, a radio base station and a radio network controller was developed to evaluate the use of Code Division Multiple Access (CDMA) for suitability for the Universal Mobile Telecommunications System (UMTS) within Europe. UMTS was to be a third generation system. In a programme led by Paul Gough (formerly of SSE) and extending over three and a half years the testbed was successfully implemented and used to support laboratory tests; it was demonstrated at the RACE II Mobile Telecommunications Summit in Cascais Portugal in November 1995. Two large racks of hardware were built and almost 100,000 lines of software were written in the realisation of the system. Initially PRL worked as subcontractors to Philips Kommunications Industrie (PKI) but became full partners in the RACE Consortium when PKI withdrew in 1993. This was a major success and those principally involved were Steve Pitchers, Andy Prentice, Dave Cattell, Andy Cloke, Dave Stanton and Paul Gough.

Another important activity was the development in the Group, by Andy Yule and the ubiquitous Paul Gough, of GPS (Global Positioning Systems) for car navigation. This built on earlier work by Mike Barnard, the possibility of consumer applications giving it a new impetus, and the system is now the subject of a Philips product activity managed by Chris Marshall. Work was also undertaken for Philips Semiconductors on digital signal processing, front-end receiver concepts and software techniques; this was to lead to the establishment of a product line and short term commercial exploitation of the technology package.

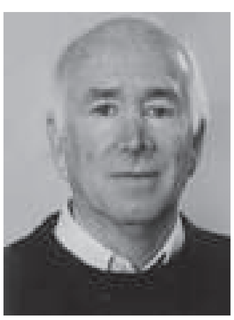
In its later years the Group was concerned with the development of a low power radio system called ZigBee for low bit-rate control applications – such as switching lights on and off. The system was designed for implementation at minimum cost and was further developed by a consortium of companies (to achieve consensus) in which Philips took the lead. The system was standardised as IEEE 802.15.4.

The group offered expertise in ASIC (Applications Specific Integrated Circuit) design

and an interesting event was their being given a contract by the SSE Division to design the CMOS column drivers required for a poly-Si based Liquid Crystal Display (and other things). The extent of the Group's expertise and their success in obtaining contracts may be gauged by the fact that in 1993 no less than 23 separate Job Numbers were allocated to the Group.

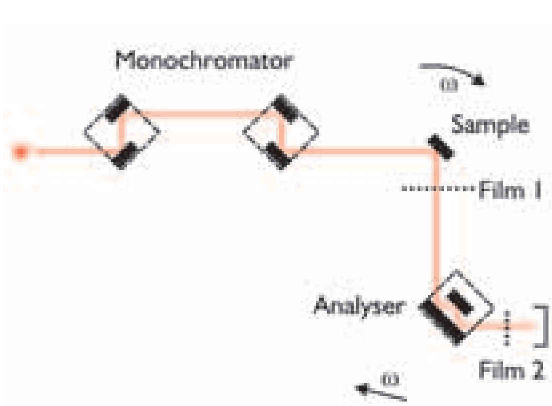
For many years Paul Fewster had been responsible for X-ray structural and topographical analysis of materials in SSE. With the termination of the Molecular Beam Epitaxy programme in 1990 the on-site demand for these facilities greatly diminished. Paul, however, had always been keenly interested in the X-ray analysis systems themselves and had modified the standard X-ray diffractometer so that it became an instrument of the highest precision in structural and topographical analysis, particularly of epitaxial layers. The modified machine was known as the High Resolution, Multi-Crystal, Multi-Reflection Diffractometer (HRMCMRD – for short) and was taken up and exploited by Philips Industrial Electronics Division who placed a contract with the Consultancy Group, to which Paul and his colleague Norman Andrew were then attached, for its further development. This fully funded work, involving both hardware and software, was extremely successful being later established as a separate activity on the site. It remained there for some time even after Philips sold its Analytical activities to Panalytical and Paul joined the new Company. He eventually moved to the Sussex University Science Park.

*Dr. Paul Fewster*



*Mr. Norman Andrew*

After some years the proportion of the work of the Consultancy Group which was undertaken for Philips Companies became such that it no longer made very good sense for the Group to operate under a different regime from that of the rest of the Laboratory. Also the pressure on numbers, a very important part of the original rationale for the Group's formation, had significantly eased. Accordingly the Group was progressively re-integrated into the normal Research framework and, in January 2000 was re-styled the Low Power Radio Group under the leadership of Dr. Chris Marshall.




*The HRMCMR diffractometer geometry*

**SSE: ACTIVE MATRIX LIQUID CRYSTAL DISPLAYS**

This was the only activity undertaken in SSE following the winding up of the Power Device work, which took place at the beginning of this period. The early phases of PRL's work in the AMLCD area were outlined in the previous chapter and it will be recalled that even at that time the work was carried on in close association with the Product Divisions, in particular that concerned with Flat Panel Displays (FPD). Negotiating Contract Research agreements in this field then was not a matter of great difficulty and the nature and course of the work was not, initially at least, abruptly changed in the new regime.

**Interactions with Japan and Korea.**

In the AMLCD field developments in the Far East, Japan in particular, proceeded so quickly in the early 90s that it became imperative for Philips to establish a partnership with a Far Eastern firm if they were to maintain an effective presence in the business. Thus in 1995 a partnership to this end was set up with Hosiden on a 50:50 basis. The new partnership was known as HAPD (Hosiden and Philips Displays) and part of the PRL display programme became focussed on supporting it. The AMLCD technology used by Hosiden was based on TFTs (not the diode technology favoured by FPD). As a result the PRL $\alpha$-Si technology programme shifted its focus back to TFTs and the PRL stafff began to experience at first hand the delights and frustrations of working with engineers from a very different culture. Many visits were made to the HAPD facility in Kobe by PRL scientists notably Ian French, Steve Deane and David Parker and the managerial interactions fell to Alan Knapp and Peter Saraga. Peter, being somewhat bigger than the average Japanese, initially experienced some difficulty in getting into their cleanroom kit when required to do so and this caused great hilarity.

The interaction with HAPD strengthened over the years with a close co-operation on $\alpha$-Si TFT technology and on display systems activity. PRL technical staff became regular visitors to Kobe and many joint research projects were established. In these projects, an example being the design of integrated row drive circuits using $\alpha$-Si technology, the PRL work was fully integrated with the Kobe development with a continuous transfer of results from research. In 1998 Philips increased its share of HAPD to 80% and Kobe became the manufacturing centre for Philips Mobile Display Systems (MDS) and at the management level Steve Battersby of PRL played a key part in establishing a strong interaction with both MDS and Kobe. Steve was in fact instrumental in starting an LTPS (Low Temperature Poly Silicon)

design activity in Kobe.

A further, albeit rather short, phase of the PRL interaction with Far Eastern display activities began in 1998 when Philips took a 50% share in the LG (Lucky Gold) AMLCD manufacturing activity in Korea to form LG Philips LCD. PRL were involved from the beginning with Alan Knapp and Ian French being concerned with what was known as the technical Due Diligence process associated with the formation of the joint activity. Research involving PRL and the Nat Lab started in 2000 and continued until 2002 on topics including:- improved moving picture quality (David Parker, David George and David Fish), micro-crystalline Si TFTs (Ian French), LTPS technology (Stan Brotherton) and work on the use of printing as a patterning technology for both the active and passive plate manufacturing. In this latter work the PRL staff, Cathy Curling, Jeff Chapman and Steve Deane, worked as the system co-ordinators and integrators. They used the extensive PRL knowledge of AMLCD design and technology to produce designs which overcame the limitations of the printing techniques thus guiding the Nat Lab printing technology work. The work done in PRL during this collaboration was of the highest quality and proved to be extremely valuable to LG. At the technical level very good relations developed between the two companies but unfortunately it eventually proved impossible to reach an agreement on the terms and conditions under which the co-operation could proceed and thus despite the good mutual understanding achieved at the technical level the co-operative work was stopped.

*Dr. Jeff Chapman*

*Ms. Cathy Curling*

**Low Temperature Poly Silicon.**

Another part of the extensive PRL programme in this field, as we discussed in the preceding chapter, was that most ably led by Stan Brotherton on poly-Si as an alternative to $\alpha$-Si. This work was continued in the early 90s and resulted in the development of a technology by means of which extremely stable devices could be made. By 1994/95 the technology was in place to allow the realisation of a range of circuits in LTPS (Low Temperature Poly Silicon). The first step was the demonstration in 1996 of a 2" diagonal high resolution display with integrated driving circuits providing a low voltage interface to the external system. This was followed in 1997 by a very high resolution (160 dots/inch) colour display having a 5" diagonal and integrated CMOS drivers.

Commercial interest in LTPS with a particular focus on mobile displays was increasing

world wide at this time and the PRL programme became directed to meeting the needs of MDS in this area. An ambitious target was the realisation of a highly integrated 1.6" mobile colour display for the so called "System on Panel" by the end of 2000. To this end Nigel Young and his colleagues developed a new low threshold voltage technology and new circuits were designed by Martin Edwards and Richard Ayres. These latter included a low voltage interface and a matrix in which each pixel contained an integrated 1-bit memory element allowing the display to operate with very low power when displaying static images. This was the most complex device ever made in the PRL clean rooms and demanded all the care and experience of Mike Trainor and his team. The first working displays were completed in late 2000 and for several years these remained the most highly integrated poly-Si displays to have been made anywhere in the world – a clear indication of the all round capability of PRL in the AMLCD field.

The next important step for poly-Si was the establishment of a LTPS design activity in the MDS facility in Kobe. Three members of PRL, Steve Battersby, Ian Hunter and Frank Rohlfing, went to Kobe in 2001 for this purpose, Steve being the first manager of the design centre. They maintained a close interaction with PRL and successfully set up a working group in Kobe returning to the UK in late 2002 by which time the Kobe group was largely self sufficient though continuing to work closely with PRL.

**Flexible Displays.**

During the mid 90s there was a good deal of interest in flexible displays and Nigel Young together with Andy Pearson initiated a programme to make an active matrix display on a plastic substrate. The work was very successful and in 1996 PRL demonstrated the world's first plastic AMLCD using a twisted nematic liquid crystal driven by thin film diodes (TFD). The work was extended to include LTPS resulting in another world first.

This pioneering work put PRL in a world leading position and resulted in many invitations to Nigel Young to present papers on the subject.

*Flexible Thin Film Display*

**Active Matrix Organic LED Displays.**

Also during this period some work was undertaken on the use of light emitting diodes based on organic materials in displays. A joint project between PRL and the Nat Lab was started on the subject in 1999 in which PRL provided the active matrix plates while the Nat Lab was concerned with the organic LED technology. Small colour displays were demonstrated in 2002 and the programme is continuing with PRL providing on-going design support. John Shannon, Nigel Young, Ian Hunter, David Fish and Steve Deane were the main contributors to this rather fascinating activity.

*An AMOLED display*

**A Three Dimensional Liquid Crystal Display - 3D LCD.**

The search for new applications of AMLCD technology was an important aim of the PRL display research during this period. An interesting example of this work was a project started by Cees van Berkel in 1993 aimed at exploring the possibility of making a 3D display based on AMLCD technology.

The approach chosen was that of making an autostereoscopic display which was realised by placing an array of cylindrical lenses in front of the LCD, the pitch and focal length of the lenses being such that pixels in different columns of the display were focussed into either the left or right eye of the viewer. With such a scheme different information can be presented to the viewer's left and right eyes and, if the information is correctly generated the impression of a 3D image is created. The approach, however, is not without its problems. In particular movement of the viewer's head results in the black mask between the pixels being imaged giving an unpleasant impression of dark bands appearing. A second difficulty is that the lens system reduces the resolution in the horizontal direction but not in the vertical direction giving another uncomfortable effect. A key PRL invention enabled both problems to be solved and this was to tilt the lens array slightly so that the axis of the

cylindrical lenses made a small angle to the columns of pixels in the display. This approach removed the black bands and enabled the vertical and horizontal resolution of the image to be made substantially equal. An additional advantage was that the assembly was made much easier as the alignment of the lens array and the display became less critical - altogether a remarkable invention.

The project took an unusual course in that, in addition to developing the technology and software for the generation of 3D images from a range of sources, application kits were made and sold to third parties with the aim of promoting the system. Cees van Berkel is pictured here with some of these kits. The kits consisted of an LCD monitor having a display fitted with the lens array, a PC to drive it and software to generate the 3D image. Reactions were favourable and considerable interest was generated in the areas of medical

*Cees Van Berkel with a 3D display*

imaging, remote sensing, CAD and games but it became apparent that, for many applications, greater resolution was required. This was a limitation, not of the 3D system, but of the AMLCD itself. Work thus effectively ceased on the topic in PRL but with the development of higher resolution LCDs the 3D system could well be revisited.

**Other Applications of Active Matrix Technology.**

From the outset of work in this area it was felt that the technology of making large area arrays of transistors on glass could have wider applications than just display. This was reflected in the name of the device group – Large Area Electronics. Ideas pursued were in medical imaging, fingerprint sensors and document scanners. Work on Flat Dynamic X-Ray Detectors (FDXD) was carried out over several years by Martin Powell and various collaborators in conjunction with Philips Medical Systems (PMS) with considerable success. A high performance 2D optical image sensor capable of imaging an A4 document was demonstrated to the Philips BoM but it was not taken up commercially because of the improvement in competing mechanical 2D scanners which were very much cheaper, if technically inferior. A capacitive finger print sensor using LTPS on glass or plastic was demonstrated in 1997 and formed the basis of a co-operative commercial activity between Philips FPD and a US company Ethentica in which PRL had a key role in the design of the sensor array and of a dedicated driver ASIC.

*2D opitical image sensor*

*Dr. Neil Bird*

These were wide ranging activities involving many people but the principal players were Martin Powell, Tony Franklin, Cathy Curling, Neil Bird, David George, Carl Glasse and Alan Knapp.

**THE END OF THE ERA**

This period came to an end with the retirement in September 2002 of Peter Saraga and we have decided that that is a good point at which to bring this History to a close. Before doing so however there are several important events that took place during this time which we should note.


*Peter Saraga being presented with a 'special' football programe marking his retirement*

There were many staff changes, some of which we have mentioned, but one, which we have not, was the retirement in May 2001 of Richard Vincent as Head of the Services and Auxiliary Sector. Prior to that appointment Richard had been Head of the Systems Division and had had a major part over many years in the ESM systems work, the success of MADGE project in particular being due to him. Richard had been a member of PRL for over thirty years, he was a great character and had made an outstanding contribution. Ray Headon succeeded Richard as Head of SAS.

In 1996 the Laboratory celebrated the fiftieth anniversary of its foundation and held Open Days to mark the event. These were extremely well organised by Ray Peacock who returned from his retirement for the purpose. Attendance at one of these Open Days was a most enjoyable, if nostalgic, experience.

*Dr. Brian Minnis*

*Dr. Paul Rankin*

Also in 1996 Peter Saraga was elected to Fellowship of the Royal Academy of Engineering as was John Shannon in 2001. A mini symposium and a luncheon party was held in the Lab to mark John's election and was attended by Peter Trier, Kurt Hoselitz, Norman Goddard, Keith Fuller, Brian Manley and John Walling, as guests, together with members of the Laboratory. In the 2003 New Year's Honours Peter was appointed an OBE which I am sure gave great pleasure in the Lab. We hadn't had very many such awards over the years (Appendix 1) and this was well deserved.

In March 2002 Martin Powell, Brian Minnis and Paul Rankin were appointed Research Fellows, as Tim Trew had been earlier, in recognition of their outstanding contributions to the work of the Laboratory over many years. John Shannon had enjoyed the same status since 1994. This position to some extent parallels the earlier

Scientific Advisers of whom we had five over the years, viz: Pieter Schagen, Steve Robinson, Eddie Kroger, Julian Beale and John Shannon.

*Dr. Terry Doyle*

Dr. Terry Doyle was appointed to succeed Peter Saraga in September 2002 but, external circumstances have dictated further reductions in the programme and staff so that at the end of 2004 the Laboratories consist of two Groups. These are the Wireless Group headed by Dr. Tobias Helbig and the Active Matrix System Design Group headed by Dr. Stephen Battersby. The Services Sector serves the whole site of which Research is a part.

Thus we conclude this History of the Mullard/Philips Research Laboratories Redhill, which, has been a story of outstanding achievement extending over nearly sixty years and we wish present and future members of the Laboratories every success in their continuing endeavours. They are heirs to a great tradition.

John Walling.

# APPENDIX ONE

## HONOURS AND AWARDS RECEIVED BY MEMBERS AND FORMER MEMBERS OF THE LABORATORY

The achievements of several members and former members of the Laboratory have been recognised over the years by the award of National, Professional and Academic Honours, Medals, Prizes and Degrees, which are listed here.

### NATIONAL HONOURS

| YEAR | NAME | TIME AT MRL/PRL | AWARD |
|---|---|---|---|
| 1965 | John Walling | 1952 – 1990 | MBE |
| 1968 | Pieter Schagen | 1955 – 1979 | OBE(Hon) |
| 1971 | Steve Robinson | 1954 – 1972 | OBE |
| 1972 | Max Smollett | 1953 – 1956 | OBE |
| 1980 | Peter Trier | 1950 – 1969 | CBE |
| 1989 | Ray Peacock | 1956 – 1995 | OBE |
| 1994 | Brian Manley | 1954 – 1969 | CBE |
| 1998 | John Williams | 1963 – 1977 | OBE |
| 2000 | Peter East | 1962 – 1982 | OBE |
| 2003 | Peter Saraga | 1964 – 2002 | OBE |

**PROFESSIONAL HONOURS**

| YEAR | NAME | TIME AT MRL/PRL | AWARD |
|---|---|---|---|
| 1976 | Steve Robinson | 1954 – 1972 | FRS |
| 1978 | Peter Trier | 1950 – 1969 | FREng |
| 1979 | Steve Robinson | 1954 – 1972 | FREng |
| 1983 | John Walling | 1952 – 1990 | FREng |
| 1984 | Brian Manley | 1954 – 1969 | FREng |
| 1985 | Norman Goddard | 1947 – 1984 | FREng |
| 1986 | Peter Mothersole | 1950 – 1972 | FREng |
| 1987 | Keith Fuller | 1956 – 1991 | FREng |
| 1988 | Brian Davies | 1956 – 1963 | FREng |
| 1990 | John Williams | 1963 - 1977 | FREng |
| 1993 | Mike Underhill | 1962 – 1984 | FREng |
| 1994 | Brian Ridley | 1956 - 1964 | FRS |
| 1996 | Peter Saraga | 1964 – 2002 | FREng |
| 1998 | Peter East | 1962 – 1982 | FREng |
| 1999 | Brian Manley | 1954 – 1969 | HonFIEE |
| 2000 | Bruce Joyce | 1969 – 1988 | FRS |
| 2000 | John Williams | 1963 - 1977 | HonFIEE |
| 2001 | Ken Board | 1969 – 1972 | FREng |
| 2001 | John Shannon | 1967 – 2003 | FREng |

For the most part these awards were made when the recipients were still members of PRL, elsewhere within the Philips Group or having fairly recently retired from Philips. In some cases though the awards were made several years after the recipient had left Philips.

These latter individuals and their positions at the time of their awards were:

Peter Mothersole: Chairman VG Electronics Ltd.

Brian Davies: Professor of Electrical Engineering, UCL.

Mike Underhill: Professor of Electronic Engineering, University of Surrey.

Brian Ridley: Professor of Physics, University of Essex.

John Williams: Chief Executive, Institution of Electrical Engineers.

Peter East: Director of Advanced Development, Racal Defence Electronics.
Ken Board: Professor of Electrical Engineering University of Wales, Swansea.
Bruce Joyce: Professor of Semiconductor Materials, Imperial College London.

A brief note concerning the Royal Academy of Engineering is perhaps not out of place, indeed Peter Trier was particularly anxious that such a note should be included and he contributed the following paragraph.

*The Academy was founded in 1976 as the Fellowship of Engineering on the initiative of the Duke of Edinburgh and a group of distinguished engineers to form a body of leading engineers to parallel and complement the function of the Royal Society in the Sciences. Having been granted a Royal Charter in 1983, it adopted its present title in 1992. Members are elected by their peers for "personal achievement of exceptional merit and distinction". The conferment of Fellowship on an individual member of the Laboratory therefore reflects great credit both on the recipient and on the Laboratory in each case. It is most noteworthy and creditable that no less than fourteen serving or former members of the Laboratory have been honoured by election to the Academy. In addition Dr. Eduard Pannenborg was elected to Foreign Membership of the Academy in 1986 and Sir Ivor Cohen to Honorary Fellowship in 1992. Brian Manley was Senior Vice-President of the Academy from 1994-96.*

The Royal Society calls for no discussion here and election to Fellowship remains the ultimate recognition of scientific achievement. In addition to the three former members of the Laboratory who have been elected to Fellowship Professor HBG Casimir was elected to Foreign Membership of the Royal Society in 1969.

## AWARDS FROM PROFESSIONAL INSTITUTIONS

### THE ROYAL SOCIETY

In 1972 Steve Robinson was awarded the SG Brown Medal of the Royal Society in recognition of his work on the MADGE system

### THE INSTITUTE OF PHYSICS

| YEAR | NAME | TIME AT M/PRL | AWARD |
|---|---|---|---|
| 1973 | Kurt Hoselitz | 1952 – 1976 | The Glazebrook Medal and Prize |
| 1977 | Ron Pearson | 1954 – 1979 | The Duddell Medal and Prize |
| 1981 | Bruce Joyce | 1969 – 1988 | The Duddell Medal and Prize |
| 1983 | John Shannon | 1967 – 2003 | The Paterson Medal and Prize |
| 1984 | Peter Trier | 1950 – 1969 | The Glazebrook Medal and Prize |
| 1985 | Colin Wood | 1970 – 1985 | The Paterson Medal and Prize |
| 1988 | Martin Powell | 1977 - 2003 | The Paterson Medal and Prize |
| 1991 | Paul Fewster | 1981 - 2000 | The Paterson Medal and Prize |

The Glazebrook Medal is one of the Institute's two premier awards and is made annually for outstanding contributions to the organisation, utilization or application of science.

The Duddell Medal is awarded annually for outstanding contributions to the application of physics.

The Paterson Medal is awarded annually to a young scientist (not more than 40 years old) for outstanding contributions to the development, invention or discovery of new systems, processes or devices, which show the successful commercial exploitation of physics. It is very pleasing that four of the first nine such awards made were to members of the Laboratory.

Brian Manley was President of the Institute from 1996-98 and John Orton and John Walling were Vice Presidents from 1990-94 and 1986-90 respectively.

**THE INSTITUTION OF ELECTRICAL ENGINEERS**

Although the Institution of Electrical Engineers awards several medals each year it is a matter of some surprise that none seems ever to have been awarded to a member of the Laboratory. Nevertheless the Institution also presents Premium Awards for the best papers published in the IEE Journals in a given year and several of these have been received by members of the Laboratory as follows:

1961: The Blumlein-Browne Willans Premium was awarded to the authors of a group of papers presented at a special IEE meeting in May 1961 devoted to the Banana Tube. The authors included Pieter Schagen, Bernard Eastwell, Nigel Calder, Ken Freeman, Richard Jackson and Harry Howden.

1970: The Blumlein-Browne Willans Premium was awarded to Ken Freeman, Richard Jackson, Steve Robinson and Peter Mothersole for their paper "Some aspects of direct television reception from satellites" published in Proc.IEE.

1985: The Institution Premium was awarded to the authors of a group of papers concerned with channel multiplier CRTs (the Falcon Tube). The authors were Daphne Lamport, Alf Woodhead, D Washington, Colin Overall, Alan Knapp, John Mansell, Pieter Schagen, Andrew Guest, Ron Gill, Roger Pook, Les Francis and Harry Stone.

1990: The Blumlein-Browne Willans Premium was awarded to Peter Saraga for his paper on "Compatible High Definition Television".

Brian Manley was President of the IEE from 1991-92 and it is noteworthy that Brian is one of the very few individuals who have been President both of the IEE and of the IoP. Peter Trier was Vice President 1974-77

We should also note that Mr. TE Goldup CBE who was Technical Director of Mullard Ltd in the forties and fifties and was much involved with the Laboratory in its early days was President of the IEE in 1957.

**THE INSTITUTION OF ELECTRONIC AND RADIO ENGINEERS -**

This Institution, now amalgamated with the IEE also made Premium Awards some of which were received by members of PRL. These are:

1981: The P Perring Thoms Premium was awarded to Mike Underhill for his paper on Wide Range Frequency Synthesisers"

1983: The Paul Adorian Premium was awarded to Richard French for his paper on "Multi Transmitter Data Systems"

1983 The P Perring Thoms Premium was awarded to Ken Freeman for his paper on "Direct Broadcast Satellite TV Receivers".

**THE INSTITUTE OF MATHEMATICS AND ITS APPLICATIONS.**

Peter Trier was President of this Institute from 1982-83.

**ACADEMIC HONOURS**

Four members of the Laboratory have been awarded senior doctorates following their submission of theses based on work mainly carried out in PRL. These are:

| | |
|---|---|
| Bruce Joyce DSc (Birmingham), | John Shannon DSc (Surrey), |
| Stan Brotherton DSc (London) | Martin Powell ScD (Cambridge) |

In addition Brian Manley was awarded Honorary DSc degrees from Loughborough, Sussex and City Universities; Brian is also a Centenary Fellow of Greenwich; Peter Trier was awarded an Honorary DTech from Brunel University in 1975.

**OTHER AWARDS**

David Allen and John Winwood were awarded the Marconi Premium of the British Institution of Radio Engineers in 1957 for their paper on "Travelling Tubes for Communications"

Pieter Schagen was elected to Fellowship of the Royal Television Society in 1976. Such a Fellowship is a rare honour awarded by the Society in recognition of outstanding achievement in the field of Television.

In 1986 Bruce Joyce was awarded the prestigious IBM Europe Science and Technology Prize in recognition of his pioneering work on Molecular beam Epitaxy. This prize was awarded to Bruce jointly with Dr. E Bauser and Dr. E Razeghi who had contributed notably to other forms of epitaxy in Companies outside Philips.

# APPENDIX TWO

## THE SUPPORT STAFF

For most of its existence the Laboratory was a large, complex and extremely sophisticated facility and its effective operation demanded very substantial infrastructure and support functions. The people who provided these facilities made a vital contribution to the work of the Laboratory but only rarely did they appear in the front line, so to speak, and I am uncomfortably aware of the fact that for the most part they have not received mention in the preceding chapters. In what follows I have attempted to note and acknowledge, albeit imperfectly, their various contributions.

### The Library.

The Library was a feature of the Laboratory from its inception. It was a truly superb facility and contributed enormously to the work of the Laboratory. That this was so was very largely due its founder librarian, Peter Ridgewell (always known as "Ridge"), a laconic, laid back, slightly rakish, pipe-smoking individual with an endless fund of doubtful stories and a remarkable gift for choosing the most appropriate and necessary books and periodicals. One of the Laboratory's most memorable characters, he was often to be observed staggering in, late on Friday evenings, burdened with cases bulging with his literary purchases. He had joined the Company in 1931 and celebrated his 40th anniversary in 1971 with a memorable party in the Canteen at which the many distinguished guests included Mr. Stanley Mullard himself.

*Stanley Mullard and Peter Ridgewell*

Ridge retired some years later being succeeded by Marjorie Patterson who, in turn, was followed by Shirley Akehurst and later by Helen Elliott. These very able young ladies introduced the inevitable computer based information retrieval techniques into the Library which, thereafter, rather sadly, diminished in size being finally wound up in 2004.

**The Secretaries.**

Until the widespread adoption of the word processor the Laboratory depended for its written output on the secretarial staff who patiently deciphered and typed the manuscripts prepared by the scientists and engineers. It was difficult for them as they did not have technical backgrounds but it was amazing how rapidly they acquired a facility in dealing with technical terms and mathematical forms.

The Director's Secretary or PA played an important part in the running of the Laboratory and, in the later days certainly, was effectively in charge of the secretarial services. Peter Trier's first PA was Mrs May Pinder, she was succeeded in 1960 by Mr. EA Stevens (Steve), who had previously been PA to Mr. T Goldup, Mullard Technical Director. Steve in his subtle way was a real power in the land and Peter Trier in particular greatly respected his judgement, Steve remained as PA to Kurt Hoselitz and retired at about the same time as did Kurt. Following Steve's departure Mrs Norah Harris took on the role (eventually) in a very firm and efficient way. Norah retired in 1980, her successor being Mrs Tessa Reeve who looked after both Norman Goddard and Keith Fuller quietly and effectively. Tessa left in about 1988 and Mrs Camille Mellor was appointed to succeed her. Camille, a dynamic and charismatic lady, very much into the new technology, had a major role in initiating the transformation of the South Site buildings, to which we referred in Chapter 8. She, in her turn, was followed as PA to the Director by Miss Karen Hickey. Mrs Stella Cox supported by Miss Sue Girling now fills the role.

Over the years the Divisions were remarkably well served by a succession of young women who brought great skill and patience to the vital task of creating the documentary output of the Laboratory. Amongst them were, Shirley Harrington, Susan Day, Pat McKellow, Beryl Roberts, Claire Knight, Sue Pond, Rosamund Jenkins, Linda McCarthy, Mandy Hall, Pam Martin, Margaret Balcombe, Stella Cox, Connie Todd, Chris Nye, Margaret Page, Valerie King, Alice Hulyer, Nicole Le Monnier, Cherie Banfield and others. Several of them as Divisional Secretaries also contributed substantially to the day to day management of the Laboratory. We were greatly indebted to all of them.

Central File was an extremely valuable facility in which all written material generated in the Laboratory was systematically classified, indexed and filed. The names which spring to mind here are those of Faye Brewer and Glenda Hunter-Rowe, remarkably dedicated and unfailingly helpful ladies. Unfortunately this unique archive was dispersed in the nineties and its contents (reportedly) transferred to optical storage media in a Concern central archive.

In the days before we had individual direct dialling all telephone calls were routed through the switchboard via the operator, a role filled for many years by Mrs Sheila Collings who was a model of efficiency, patience and unfailing courtesy, a great asset to the Lab. On her retirement the telephonist's function was added to the responsibilities of the receptionists, Joy Istead, Pam Foote and Pauline Boyd, but, by then, direct dialling was pretty well universal.

**The Engineers.**

The importance of the part played by the Engineering Division in the work of the Laboratory will, I hope, be apparent from the preceding chapters and some of the outstanding contributions made by members of the Division over the years have been noted. Nevertheless, there were many unsung heroes who spent a major part of their working lives in the Laboratory and helped not only to create its output but also to shape its life and character. Amongst those whom I remember particularly but who have not been mentioned elsewhere are David Atkinson, John Baker, Peter Charman, Phil Cheale, Brian Fairchild, John Francis, Des Frost, Charlie George, Fred Hall, John Hankin, Mick Martin, Ken Mudd, Eddie Pitt, John Sapp, Ted Skipp, Basil Stanley, John Taylor, Don Tindall, Brian Uwins and Peter Whittier from the Workshop (later known as the Mechanical Techniques Department). Jim Morrison, Geoff Lelievre, Charlie Grimble, Ben Benham, Bill Baxter, Doug Mainard and Terry Woodger were designers and draughtsmen who made memorable contributions. In the early days Geoff and Charlie, together with Dennis Peto, also had major roles in devising and presenting the annual MRL Concert. This was held in the Colman Institute in Redhill (demolished many years ago) and was a great and most memorable feature of the social life of the Laboratory.

The Technology Department evolved as chemical processes became increasingly important in device and circuit fabrication and, headed by Ron Jeanes, who had spent the earlier part of his career in CML Mitcham, it was a most valuable, indeed crucial, facility. Its members most of whom we have not mentioned elsewhere, included Ted Curran, Ken Day, Ron Gill, John Marsh, John S Page, Ulrich Pick, Ray Ormerod, Harry Sewell, Willy Watts, Eric Webb, Peter Webb and Roy Winkle. They were most resourceful and creative. The Laboratory's photographers were also part of this department. They, Norman Dunford, Colin Chapman and Richard Williams were all long serving members of the staff and played a vital part in making and maintaining records of equipment and staff and in the preparation

of publications. Indeed the superb photographic archive, which they created, has been indispensable in the preparation of this history.

Quite early on in the life of the Laboratory the Apprentice School was established, it provided outstanding training and was for many years an excellent source of skilled engineering staff. Ron Fenner and Geoff Couchman were its original guiding lights and they were followed by Brian Fairchild and John Hankin prior to the school's being wound up in the 1980s.

**The Glass Shop.**

Glass technology was a crucial part of valve engineering and the Glass Shop, then headed by Harry Flood came to Salfords in 1948 with the Vacuum Physics Laboratory. They were amazingly skilful and had a crucial role in the tube and display work undertaken over the years in the Laboratory and in the construction of intricate, specialised equipment required for experimental work in the laboratories. Harry Flood went to Southampton with JA Jenkins in 1956 and he was succeeded by John Balcombe, who later joined IT&T in the USA, and Ron Charteris. Ron was indefatigable in seeking to keep abreast of glass and ceramic technologies and travelled widely in their pursuit. Other leading lights in the area were Stuart Tilford, John Clements, who was a great support to the Channel Multiplier team, and Keith Wornham. Keith in particular had, in addition to outstanding technical skills, a genuine artistic talent, which was often deployed in making mementoes for members of the Laboratory celebrating 25th and 40th anniversaries or retiring. In the early days of the Laboratory the Christmas celebrations tended to be somewhat bacchanalian and the glass shop members armed with musical instruments made for the occasion paraded round providing a rather raucous, but memorable, seasonal background.

**The Maintenance Department.**

The maintenance staff were responsible for the good order of the buildings and the complex services required for the efficient operation of the increasingly sophisticated equipment and facilities within the Laboratory. The department was managed successively by Terry O'Donoghue, Jim Wood, Arthur Jackson and Ray Headon, they were sound practical men, flexible and helpful and the department included many great characters who, sometimes literally, shaped the Laboratory. Amongst them one remembers gratefully Harry Hoy, Frank Collar, Ron Hopper, Harry Halstead, Jim Ford, Gill Hockett, Wally Bone, Ted Lyon,

Sid Acton, Ray Felgate, Ben Ware and, by no means least, Malcolm Christmas and over the years there were many others. They rose to the occasion, perhaps never more so than when the Anelva machine was installed in G Block in 1988. Then they worked literally night and day over a weekend to ensure that all the complex facilities required by the machine were in place when the Japanese engineers arrived on the Monday morning. They were altogether quite splendid.

**The Instrumentation Department.**

The work of the Laboratory was totally dependent on a vast number of sophisticated instruments and equipment mainly bought from outside specialist suppliers although some were constructed in-house. The recording and maintenance of this equipment was the concern of the Instrumentation Department. In the early days this was presided over by Mr. Pullin (whose first name I never knew), the department was referred to as the Pullinery and continued to be long after Pullin himself had retired. Amongst the staff in the early days were Mr. Sargeant (Sarge) and Ray Dench, an enthusiastic motorcyclist. When Mr. Pullin retired Brian Evans assumed responsibility for the department and when Brian left in 1985 Ray Headon took over. The departmental stalwarts in the later days were Axel Andersson-Gylden, John Baillie, David Body, Bob Doddington, Chris Saveker and Colin Young; Paul Walters too had, and has, a crucial role in keeping the myriad PCs in good order. Altogether this was a most valuable, indeed a vital, facility for the Laboratory.

**The Administration, Purchasing and Personnel Departments.**

The Administration or Accounts department was vital to the smooth running of the Laboratory. It was efficiently managed by a succession of Chief Accountants (Financial Controllers) - Mr. Higgins, Bunny Munns, John Day, Zbig Kowzan, Keith Kirby and Brian Lugg and they were ably supported by a small team, some of whom spent most of their working lives in the role. I don't remember all of them but they included Margaret Brantom, Gwen Croot, Chris(tine) Ringrose and, for many years, Dennis Cox who started out as a member of Vacuum Physics and transferred to Accounts, some years later he became my right hand man as SSE Divisional Administrator. Staff sales formed part of this department but it was not until the 60s or 70s that a real staff shop was set up. Originally in the Canteen, where it operated under the benign aegis of Beryl Marsh and then Shirley Child, it moved to the enlarged South side foyer, where it was looked after by Mrs Terry Shah.

Purchasing had a similarly important function; we bought a great deal of specialist gear and materials and getting the right thing at the best price called for tremendous acumen, experience and know how. We were well served indeed by the Purchasing Department headed successively by Jack Theobald, Pat Pleasance, Jim Seymour and Colin Owen. I didn't know Mr. Theobald personally but the others were unfailingly pleasant, efficient and helpful and were backed up by very competent staff who included Ken Swain, Dennis Peto (at one time) and also Colin Owen. They were just great.

The Personnel Department, being responsible for the organisation of staff recruitment and indeed all staff matters were also vital to the operation of the Laboratory. We were well served by our Personnel Managers and their staff, the Managers were George Taylor, Alan Ahern, Vic Paynter, Mike Malpass, Richard Turner, Frank Stewart, Ann Redfearn, Brian Goddard and Stephen Pearn. The support staff included Miss Renate Warner, amazingly efficient and energetic, Chris(tine) Nye and Dennis Budgen, a former member of SSE who had worked on Chromatogaphy in the Materials Group. Interestingly Dennis was not the only member of the Chromatography team who moved to the Personnel function as Dr. Bill Miller, the original team leader, and Dr. FW (Eric) Wilmott did so as well, joining the Philips UK Central Personnel Department and pursuing successful new careers. The Medical department came under the aegis of the Personnel Department and it was staffed by a Registered Nurse. None of us who knew her will forget Miss Mahoney, a brusque Irish lady with a heart of gold; she was followed by the gentler but equally efficient Liz Burgess. Many of us had cause to be very grateful to each of them for their help and wise advice.

The Gatehouse staff had a vital function in ensuring the security of the Laboratory at all times and they did so over the years with remarkable efficiency and unfailing courtesy.

**The Canteen.**

The Canteen, vital to any organisation and the Laboratory was no exception, operated under a succession of managers who reported to the Plant Manager; I don't remember all of them but they included Mr. Dix, Mr. Smith, Bob Daus, Peter Eaton, Steve Gosson and Peter Cresswell. In the early days one bought tickets and exchanged them for food of various sorts, lunch, I recall required a 1/- ticket sold at a serving hatch by Mr. Dix. Later we had a more rational system of a till which for many years was operated by a very efficient lady, Mrs Bond. Tea trolleys were a feature of the early days, loaded with pastries, proper cups and a tea urn they came round each morning and afternoon pushed by dedicated ladies from

the Canteen. They were delightful, unique sources of news and gossip and genuinely interested in the staff. None of us who were privileged to know them will forget Ivy, Sylvia, Dolly and their colleagues. It was a sad day indeed when they were replaced by the soulless automata we know today. Altogether the Canteen was a great asset to the Laboratory.

These then were the support functions without which the Laboratory could not have operated at all; we acknowledge their vital contribution with admiration and sincere gratitude.

# APPENDIX THREE

## ACRONYMS

Acronyms have come to be accepted as an integral part of the communications culture of the twentieth and twenty-first centuries. Electronics has spawned a vast number of them and they are now essential to normal communication in the discipline. This book inevitably therefore contains a large number of Acronyms, some of which may be unfamiliar to those who have not been concerned in a particular specialist area, and I have therefore compiled this glossary of those used in the book. In some cases the Acronym has been defined in the text and used only once and in those cases I have probably not included it here. I hope that the list is helpful and I apologise for any errors and omissions.

| | |
|---|---|
| ABS | Antilock Braking System |
| ACTP | Advanced Computer Technology Project (Min Tech) |
| ADSL | Asynchronous Digital Subscriber Link |
| AEI | Associated Electrical Industries (UK) |
| AERE | Atomic Energy Research Establishment |
| AI | Artificial Intelligence |
| AMLCD | Active Matrix Liquid Crystal Display |
| APD | Applied Physics Division |
| ASE | Admiralty Signal Establishment |
| ASIC | Applications Specific Integrated Circuit |
| ASM | Associated Semiconductor Manufacturers Ltd. (Philips) |
| ASRE | Admiralty Signals and Radar Establishment |
| ASW | Acoustic Surface Wave(s) |
| BOC | British Oxygen Company |
| BT | British Telecomms Ltd |
| BTL | Bell Telephone Laboratories |
| BWO | Backward Wave Oscillator |
| CCIR | International Radio Consultative Committee |
| CD-I | Compact Disc-Interactive |
| CDROM | Compact Disc Read Only Memory |

| | |
|---|---|
| CEGB | Central Electricity Generating Board |
| CERN | Centre Européen de Recherche Nucléaire |
| CEO | Chief Excutive Officer |
| CML | Central Materials Laboratory (Mullard) |
| CMOS | Complementary MOS ie n and p devices on the same slice |
| CMT | Cadmium Mercury Telluride |
| CODIT | Code Division Testbed |
| CDMA | Code Division Multiple Access |
| CPA | Circuit Physics and Applications (Division) |
| CRB | Concern Research Bureau |
| CRT | Cathode Ray Tube |
| CSF | Compagnie Général de Télégraphie sans Fil |
| CTO | Chief Technology Officer |
| CVD | see DCVD |
| DBS | Direct Broadcast Satellite |
| DCVD | Department for Co-ordination of Valve Development, later Department for Components, Valves and Devices (MOD) |
| DECT | Digital European Cordless Telephone |
| 2-DEG | Two Dimensional Electron Gas |
| DLTS | Deep Level Transient Spectroscopy |
| DMOS | Double Diffused MOS |
| DRA | Defence Research Agency (UK Government) |
| DSAC | Defence Scientific Advisory Council (see also ERC) |
| DSW | Direct Slice Writing |
| DTI | Department of Trade and Industry (UK Government) |
| DVD | Digital Video Disc |
| EBM | Electron Beam Machine |
| EBPG | Electron Beam Pattern Generator |
| EBU | European Broadcasting Union |
| ECCM | Electronic Counter Counter Measures |
| ECH | Eddy Current Heater |
| EIP | Electron Image Projector |
| ERC | Electronics Research Council (later DSAC) (MOD) |

| | |
|---|---|
| ESM | Electronic Support Measures |
| FDM | Frequency Division Multiplexing |
| FET | Field Effect Transistor |
| FMCW | Frequency Modulated Continuous Wave (Radar) |
| FPD | Flat Panel Display (Group) a Philips Product Group |
| GCHQ | Government Communications Headquarters (MOD) |
| GEC | General Electric Company (UK) |
| GPO | General Post Office (UK) |
| GSM | Groupe Spéciale Mobile (Telephone) |
| HAPD | Hosiden and Philips Displays |
| HDTV | High Definition Television |
| HEMT | High Electron Mobility Transistor |
| HEXFET | A Double Diffused Power MOS technology (International Rectifier) |
| IBM | International Business Machines Inc. (US) |
| IC | Integrated Circuit |
| ICST(M) | Imperial College of Science, Technology (& Medicine) University of London |
| I&E | Industrial Equipment Division of Philips |
| IEE | Institution of Electrical Engineers |
| IEEE | Institute of Electrical and Electronic Engineers (US) |
| IERE | Institution of Electrical and Radio Engineers |
| IFM | Instantaneous Frequency Measurement |
| $I^2L$ | Integrated Injection Logic |
| IKBS | Intelligent Knowledge Based System(s) |
| ILS | Instrument Landing System |
| INMOS | A Government sponsored UK Microelectronics Company |
| IPS | Intelligent Power Switch |
| IRC | International Research Co-ordinator (Philips) |
| IRC | Interdisciplinary Research Centre (UK Universities) |
| ISA | Institute for Systems Automation (Philips UK) |
| IST | Institute for Software Technology (Philips Nat Lab) |
| JEOL | Japan Electro-Optic Company Ltd. |

| | |
|---|---|
| LCD | Liquid Crystal Display |
| LCTV | Liquid Crystal Television |
| LED | Light Emitting Diode |
| LEP | Laboratoire d'Electronique et de Physique Appliquée (Philips) |
| LPE | Liquid Phase Epitaxy |
| LTPS | Low Temperature Polysilicon |
| MAC | Multiplexed Analogue Components |
| MADGE | Microwave Digital Guidance Equipment |
| MBE | Molecular Beam Epitaxy |
| MDS | Mobile Display Systems (Philips) |
| MEL | Mullard Equipment Ltd (originally), later MEL Ltd (Philips UK) |
| MERL | Mullard Electronic Research Laboratory |
| MESFET | Metal/Semiconductor FET – a Schottky gate FET |
| MMCD | Multimedia Compact Disc |
| MOD | Ministry of Defence |
| MOSFET | Metal/Oxide FET |
| MOST | Metal Oxide Semiconductor Transistor |
| MPEG | Moving Picture Expert Group |
| MQW | Multiple Quantum Well (structure) |
| MRL | Mullard Research Laboratories |
| NCM | New Concern Mobile (radio) |
| NIRNS | National Institute for Research in Nuclear Science |
| NMR | Nuclear Magnetic Resonance |
| NPL | National Physical Laboratory |
| NTD | Neutron Transmutation Doping |
| NTSC | National Television Standards Committee (US) |
| NZIF | Near Zero IF |
| OCR | Optical Character Recognition |
| OCTU | Officer Cadet Training Unit |
| PAL | Phased Alternate Lines |
| PC | Personal Computer |
| PCB | Printed Circuit Board |
| PCM | Pulse Code Modulation |

| | |
|---|---|
| PEAB | A Swedish Philips Company |
| PIN | A semiconductor device having a p-i-n structure |
| PIPS | Philips Intelligent Power Switch process |
| PL | Photoluminescence |
| PLE | Photoluminescence Excitation (Spectroscopy) |
| PMS | Philips Medical Systems |
| PTI | Philips Telecomunicatie Industrie |
| PMC | Production Management Committee (Philips UK) |
| PMR | Private Mobile Radio |
| PPC | Programme Planning Committee (PRL) |
| PRL | Philips Research Laboratories |
| QMC | Queen Mary College, University of London |
| QW | Quantum Well |
| RAE | Royal Aircraft Establishment (MOD) |
| RCA | Radio Corporation of America |
| RHEED | Reflection High Energy Electron Diffraction |
| RRE | Radar Research Establishment (MOD) |
| | (later Royal Radar Establishment ) |
| RSRE | Royal Signals and Radar Establishment (MOD) |
| RTC | La Radiotechnique Compelec (French Philips Components Co.) |
| SAS | Support and Auxiliary Sector |
| SEM | Scanning Electron Microscope (Microscopy) |
| SERC | Science and Engineering Research Council (UK) |
| SERL | Services Electronic Research Laboratory (MOD) |
| SIMS | Secondary Ion Mass Spectrometer (Spectroscopy) |
| SIPMOS | A Siemens Power MOS Technology |
| SSE | Solid State Electronics (Division) |
| SSP | Solid State Physics (Division) |
| SSR | Secondary Surveillance Radar |
| TDM | Time Division Multiplexing |
| TEM | Transmission Electron Microscope (Microscopy) |
| TFD | Thin Film Diode(s) |
| TFT | Thin Film Transistor |

| | |
|---|---|
| TMC | Telephone Manufacturing Company (Pye) |
| TRAPATT | Trapped Plasma Avalanche Triggered Transit (oscillator) |
| TRE | Telecommunications Research Establishment (MOD) |
| TTL | Transistor Transistor Logic |
| TWM | Travelling Wave Maser |
| TWT | Travelling Wave Tube |
| UCL | University College, London |
| UMIST | University of Manchester Institute of Science and Technology |
| VPD | Vacuum Physics Division |
| VPE | Vapour Phase Epitaxy |
| VPL | Vacuum Physics Laboratory |
| V/STOL | Vertical/Short Take Off and Landing (Aircraft) |
| YAG | Yttrium Aluminium Garnet |
| YIG | Yttrium Iron Garnet |

# APPENDIX FOUR

The names of those appearing in the photograph on page 160 *Applied Physics Division at the time of Pieter Schagen's retirement* are as follows:

Standing: back row left to right.
MJ Powell, AG Knapp, D. Washington, AR Franklin, RAW Young, JL Page (SSE), D Hood, KJ Wood, LG Pittaway, BK Herbert, JMS Schofield, RF Hall,, R Bridgen, SF Tilford, MJ Plummer.

Standing: second row left to right.
K Woodbridge, DH Nicholls, BW Nicholls, GK McGinty, T Chisholm, IR Clarence, R Ward, R Pook, JR Mansell, HD Stone, AJ Jenkins, C Todd, DG Simmons, WM van Alphen (NatLab), AJ Fox, AJ Guest.

standing: first row left to right.
M Brannen, JN Sandoe, PA Miller, AD Martin, PW Whipps, BJ Goldsmith, JP Beasley, D Mistry, BJ Stocker, SJ Eden, CD Mayne, DL Lamport, JA Clarke, J Smith, ED Roberts, JA Chapman.

Seated: front row left to right
FT Buhlmann, JW Young, JW Orton, HNG King, L McCarthy, P Schagen, AW Woodhead, ME Hall, AA Turnbull, GF Weston, GWR Charteris, BF Martin.

The names of those appearing in the photograph on page 227 *Bertus Pals and Solid State Electronics Division June 1993* are as follows:

Standing: back row left to right.
I French, J Gowers, S Deane, J Hewett, JA Chapman, S Battersby, EB Eves, MJ Powell, S Higgins, A Pearson, C van Berkel, D McCulloch, AR Franklin, C Glasse, I Stemp, B Clegg, R Wilks.

Standing: first row left to right.
A Gupta, A Goodyear, ND Young, JR Hughes, BF Martin, C Glaister, B McGarvey, ES Eilley, I Clarence, A Gill, M Trainor, T Curran, K Hutchings, DH Paxman, R Ayres, N Andrews.

Seated: front row left to right.
A Wishart, J Sandoe, J Ross, CA Fisher, N LeMonnier, JM Shannon, JA Pals, DJ Coe, P Fewster, CJ Curling, D Theobald, PA Gough, SD Brotherton, I Gale.

The names of those appearing in the photograph on page 238 *The Consultancy Group in 1992* are as follows:

Background: left to right.
P Jamieson, P Simons, P Relph (seated), S Pitchers, N LeMonnier, A Yule, A Hulyer, S Thomas (seated), P Beasley, DG Simmons, A Stove.

Foreground: left to right.
M Healey, B Minnis, A Prentice, RJ Murray.

# POSTLUDE

All who have known and admired the Research Laboratories will have found this a fascinating story and an important record of the science and technology carried out there over the past 60 years. For those of us who have been privileged to have worked there, these pages also brought flooding back the memories of colleagues and friends and of the wonderful spirit that has imbued the place throughout.

At one level this book is a catalogue of events, projects and people engaged in research over that time. At another level it is an adventure story telling of the determination, enthusiasm and inventiveness of a small group of scientists whose initiative led to the development of one of the most successful industrial research laboratories in the world and a star in the Philips crown.

During its lifetime the Laboratories have had to adjust to an ever changing environment. At its beginning after the Second World War the task was to re-invent and re-establish the product base of Mullard Limited; with the European economy ravaged by war, the company readied itself to play an important part in the recovery of Philips.

It is difficult now to recapture the national self-confidence of Britain emerging victorious from the Second World War. Success had hinged upon a long heritage of industrial capability harnessed to the newer opportunities opened up by science and technology. Britain in partnership with the USA led the world in the newly emerging physics based industries of power, electronics, aeronautics and computing. It was in that heady atmosphere that the Laboratories began. The scientists who brought it about were already eminent in their own right. The Mullard management that supported the endeavour were remarkably far-sighted. During those early phases much was achieved. Mullard established its credentials in many of the newly emerging electronic technologies: semi-conductors, radar, microwave devices, night vision, support to the burgeoning nuclear industries and

electronic detectors of many kinds. Its leadership in television technology was strengthened. The Laboratories created fresh opportunities; new factories were opened and existing facilities extended. The Research Laboratories expanded and fed both people and products into these major new productive resources; Mullard thrived.

It took time for Philips to appreciate what had been achieved in Britain and the potential that the Laboratories held for the Concern. Hendrik Casimir, the great architect of Philips research, saw the opportunity and his decisions, pressed upon him by Peter Trier, led to the Mullard Research Laboratories beginning to fulfil its full potential within the Philips Concern.

The stage had been set, but the picture continued to develop and change. The global development of the Company led to the establishment of research resources worldwide; programmes had to be more closely tailored to capitalise on knowledge wherever it existed. Competition around the world brought new priorities; research needed to be more sharply focused. Increasing cooperation and partnership in technological areas allowed a sharing of knowledge and resources; no longer was it necessary to do everything within the one Company. The Research Laboratories responded to every one of these changes and the adjustments were not always easy; some required expansion while others painful reduction, but always accompanied by the overriding need to match the programmes to the developing Concern needs. This record describes all these developments fairly and critically; John Walling whose distinguished career at the Laboratories spanned much of this period, has told the adventure story as few others could have done. All those whose names and work are honoured here should be proud; there are many others whose valuable contribution is not recorded. They all share the honours in this story of a great laboratory.

In the years covered by this history, fortunes have varied but the Concern's commitment to research has not. As a direct consequence Philips has been one of few global companies to have remained in the forefront of the world of electronics for close on hundred years. Let us hope that the wisdom that from its inception led Philips to invest in knowledge as the core of its business does not waver in the years to come.

Brian Manley CBE FREng

UK Board Member for Research 1983 - 1986

Back cover:

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